ELECTRICAL ENGINEERING

DECEMBER 1960
Vol. 79, No. 12

COVER design by Robert Nunney, Artists Studios, Inc., Cleveland, Ohio. It depicts a missile launched from a large known base into the unknown blackness of space toward a tiny planet—a flight made possible by electrical engineering. Cover courtesy of Jack & Heintz, Inc.

Contents

Aerospace Problems 959

An Engineer Looks at Space Flight *K. J. Bossart* 960

Space flight from the perspective of the engineering disciplines, and an evaluation of its potential benefits

Thermoelectricity Application Considerations *A. A. Sorensen* 963

Some considerations for space, terrestrial, and marine applications of thermopiles are presented

Experimental Solar Thermionic Converter for Space Use *H. Oman, G. Street, Jr.* 967

A high-pressure cesium-vapor thermionic converter appears to be a promising source of power for space vehicles

Magneto-Thermionic Power Generation *A. Schock* 973

A design concept to increase the efficiency of thermionic generators, under certain conditions, by a magnetic field perpendicular to the electrode surface

Design of a Solar-Powered Thermionic Diode *W. J. Leovic, M. W. Mueller* 979

A discussion of a concerted effort that is underway to develop a solar-powered diode for use in space or at remote ground stations

Magnetohydrodynamic Orbit Control for Satellites *S. T. Demetriades* 987

A discussion of some of the merits and design considerations of magnetohydrodynamic propulsion systems for satellites

The Effect of Variable Plasma Conductivity on MHD Energy Converter Performance *W. B Coe, C. L. Eisen* 997

The magnetohydrodynamic energy converter provides a means for converting some of the kinetic and thermal energy of a plasma directly into useful electrical work

Precise-Frequency Power Generation from an Unregulated Shaft *K. M. Chirgwin, L. J. Stratton, J. R. Toth* 1005

The system described generates precise-frequency power through use of a brushless generator, a semiconductor frequency changer, and other devices

Application of Cryogenics to Electrical and Electronic Design *R. J. Allen* 1013

A discussion of some low-temperature phenomena pertinent to the field of electrical and electronic design

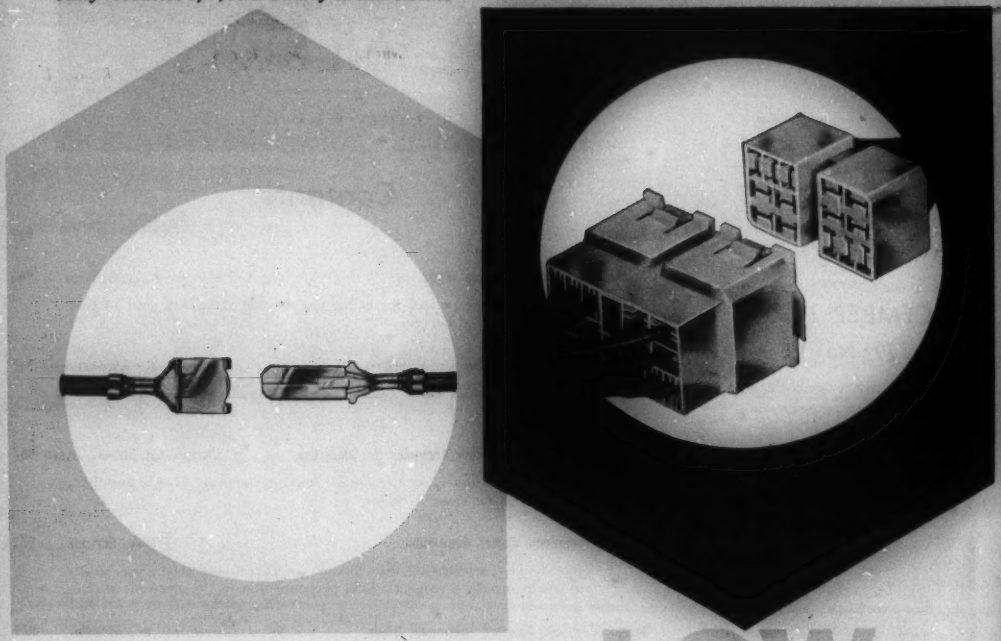
CONTENTS CONTINUED

Published monthly by American Institute of Electrical Engineers

ELECTRICAL ENGINEERING, © Copyright 1960 by the American Institute of Electrical Engineers, printed in the United States of America; indexed annually by the AIEE, weekly and annually by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York 18, N.Y., by the first of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

HIGH

20-25 amperage rating for greater design flexibility . . . choice of 7, 14 or 20 way circuit blocks.



LOW

2-5 pounds insertion and extraction force for easier installation and servicing.

NEW AMPEEZ CONNECTOR GIVES YOU BOTH

Here is a workhorse of a connector! Housed in tough nylon and designed to carry as many as 20-circuits while holding insertion-extraction forces to 2-5 pounds, AMPEEZ Connectors are adaptable to many applications calling for a heavy-duty, easily serviced multiple-circuit disconnect.

AMPEEZ Connectors will match your application needs perfectly . . . anything you call for up to 20-circuits and 25 amps. One other major feature! *AMP's exclusive Tab-Gap Lok assures a constant contact pressure even under the severest vibration conditions.*

Use AMPEEZ Connectors, eliminate the human error in individual connections . . . make them fast and safe. Send today for AMPEEZ Connector literature and sample of tab and receptacle with Tab-Gap Lok.

AMP INCORPORATED

GENERAL OFFICES: HARRISBURG, PENNSYLVANIA

AMP products and engineering assistance are available through subsidiary companies in: Australia • Canada • England • France • Holland • Italy • Japan • West Germany

Contents Continued . . .

Prediction of Transient Thermal Environments in Space Vehicles — *T. Ishimoto, B. W. Randolph* — 1019

Transient thermal envelopes induced within space vehicles by conditions external to the earth's atmosphere are considered

Electrical System Transients and Sensitive Circuit Control — *T. B. Owen* — 1023

Methods of controlling the coupling of transient impulses into sensitive circuits are described

One-Point Ground System with R-F Shielding and Filtering — *R. A. Varone* — 1028

An organized plan has been developed for handling the grounding, shielding, and filtering of missile electronic systems

Evolution and Testing of a Navigational Satellite — *M. A. Schreiber, T. Wyatt* — 1033

A passive world-wide, all-weather navigating system based on orbital parameters derived from the Doppler shift of satellite signals

Use of Moon or Satellite Relays for Global Communications — *L. P. Yeh* — 1043

Advantages and limitations of moon and satellite relays as means to extend the range of global communications

Radiation Shielding for Space Vehicles — *J. W. Keller, N. M. Schaeffer* — 1049

Problems in shielding manned vehicles from previously unknown radiations in space are discussed

Technical Paper Digests

Flux Pattern Instrumentation Using Hall Probes	*H. Hollitcher*	996
Nonlinear Servomechanism of Limited Dynamic Range	*R. L. Moruzzi, F. B. Tuteur*	1041
Rainfall Resistivity and 60-Cycle Insulator Flashover	*R. J. Mater, M. G. Poland*	1042

Departments

Institute Activities	1055		
Engineering Societies Personnel Service, Inc.	46A		
Of Current Interest	1074		
New Books	1082	Industrial Notes	33A
Technical Literature	1084	Trade Literature	44A
New Products	8A	Index to Advertisers	52A

Statements and opinions given in articles appearing in *ELECTRICAL ENGINEERING* are expressions of contributors for which the Institute assumes no responsibility. Correspondence is invited on controversial matters. Published monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

Headquarters, 10th floor • Editorial Offices 6th floor

33 West 39th Street, New York 18, N. Y.

C. H. LINDER, President — N. S. HIBSHMAN, Secretary

PUBLICATIONS DEPT., W. F. Denkhaus, *Chairman*; H. N. Muller, Jr., *Vice-Chairman*; C. S. Rich, *Secretary*; D. T. Braymer, T. H. Cline, Charles Concordia, Burke Frick, L. R. Gaty, R. B. Gear, Lenine Gonsalves, E. T. B. Gross, W. R. Harris, D. L. Hemmenway, A. W. Kessler, C. W. Leihy, L. F. Lewis, M. S. Merritt, F. W. Norris, F. C. Roberts, J. D. Tebo, J. J. Tesar, P. G. Wallace, B. James Wilson.

ELECTRICAL ENGINEERING Published monthly by the American Institute of Electrical Engineers publication office Hildreth Press, Bristol, Conn. Editorial and advertising office, 33 West 39th Street, New York 18, N.Y. Member subscription $6 per year nondeductible from dues; single copy 75 cents. Nonmembers subscription $12 per year plus extra postage to all countries to which second-class postage rate does not apply; single copy $1.50. Entered as second-class matter at the Post Office, Bristol, Conn., under the Act of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P. L. & R. Act of February 28, 1925. December 1960: Vol. 79, No. 12. Number of copies this issue, 65,000.

Charles S. Rich
Editor and Manager of Publications

G. C. Baxter Rowe
Associate Editor

Editorial Assistants

J. M. Carlinsky

G. Charitz

A. M. Fallert

G. Jaari

S. Walters

R. E. Whitlock

Advertising

J. S. Lopes
Middle Atlantic Manager
33 W. 39 St., New York 18, N.Y.
Tel: PEnnsylvania 6-9220

J. S. Holzer
Eastern Manager
33 W. 39 St., New York 18, N.Y.
Tel: PEnnsylvania 6-9220

E. R. Bollinger
Central Manager
3758 Cleveland-Massillon Rd.
West Richfield, Ohio
Tel: OLiver 9-4800

A. E. Del Gado
Mid-West Manager
1604 Chicago Ave.
Evanston, Ill.
Tel: GReenleaf 5-1132

T. P. Galavan
A. O. Dillenbeck, Jr.
Western Adv. Office
266 South Alexandria Ave.
Los Angeles 4, Calif.
Tel: DUnkirk 5-3991

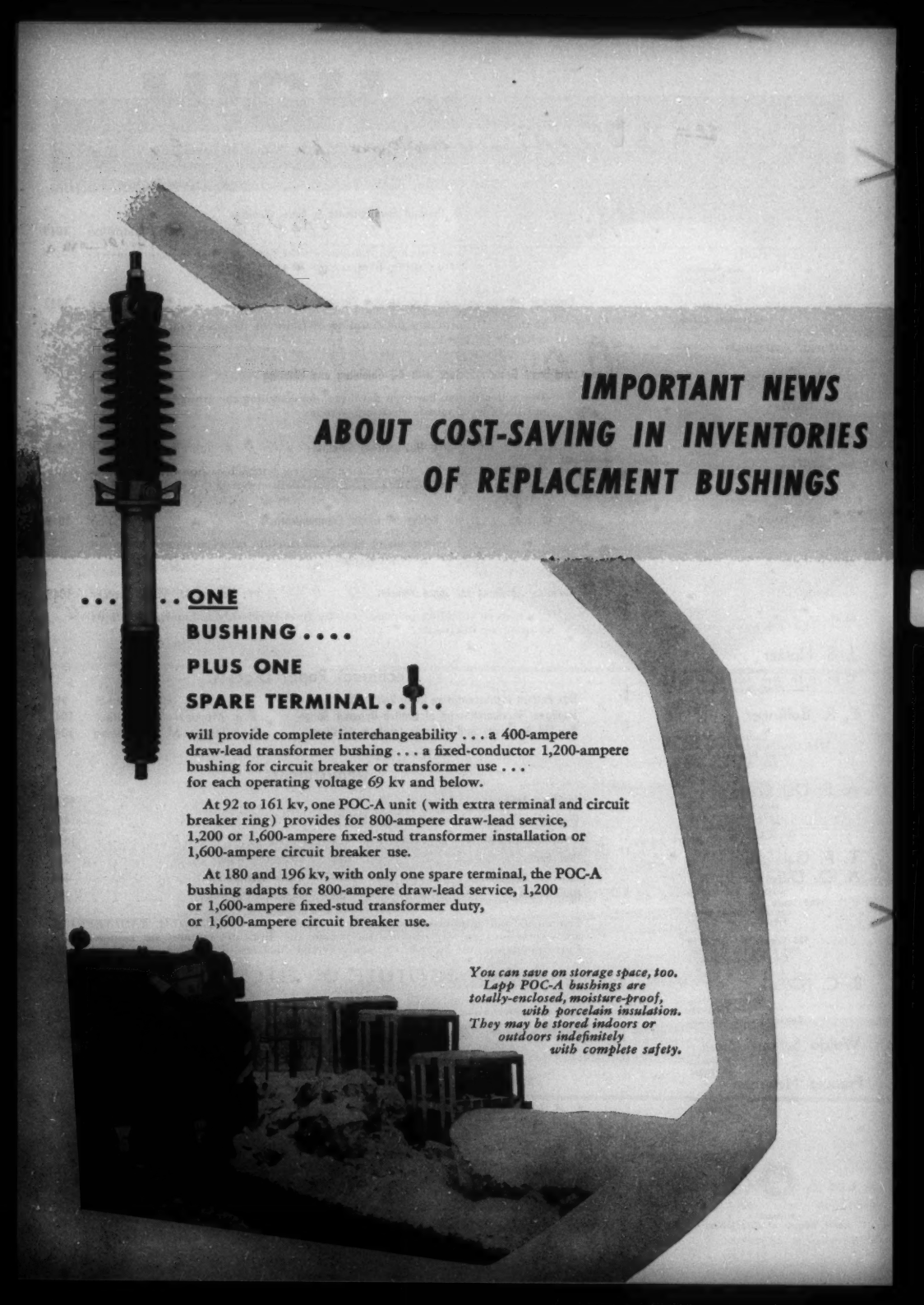
333 Kearny St., Rm. 310
San Francisco 8, Calif.
Tel: EXbrook 2-4073

B. C. Nichols
European Office
151 Fleet St.
London E.C. 4, England

Waldo Schraubstader
Market Research Director

Frances Newman
Advertising Production Manager

ABC
Member
Audit Bureau of Circulations



IMPORTANT NEWS ABOUT COST-SAVING IN INVENTORIES OF REPLACEMENT BUSHINGS

. . . . . **ONE**

BUSHING . . . .

PLUS ONE

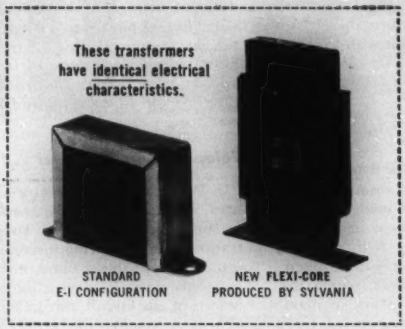
SPARE TERMINAL . . . .

will provide complete interchangeability . . . a 400-ampere draw-lead transformer bushing . . . a fixed-conductor 1,200-ampere bushing for circuit breaker or transformer use . . . for each operating voltage 69 kv and below.

At 92 to 161 kv, one POC-A unit (with extra terminal and circuit breaker ring) provides for 800-ampere draw-lead service, 1,200 or 1,600-ampere fixed-stud transformer installation or 1,600-ampere circuit breaker use.

At 180 and 196 kv, with only one spare terminal, the POC-A bushing adapts for 800-ampere draw-lead service, 1,200 or 1,600-ampere fixed-stud transformer duty, or 1,600-ampere circuit breaker use.

You can save on storage space, too. Lapp POC-A bushings are totally-enclosed, moisture-proof, with porcelain insulation. They may be stored indoors or outdoors indefinitely with complete safety.


These transformers have identical electrical characteristics.
STANDARD E-I CONFIGURATION
NEW FLEXI-CORE PRODUCED BY SYLVANIA

Radically new in concept! Radically different in construction! Radically smaller and lighter! That's the dramatic news in the Sylvania Flexi-core transformer. And for the design engineer, Flexi-core opens up whole new design possibilities.

Thanks to this new core construction, Sylvania can now make transformers *up to 30% smaller and lighter than types now in use!* Odd size and special shape transformers can be made without the usual penalties in cost and delivery. *RESULT:* the design engineer can make the sweeping changes he desires and still stay within budget restrictions.

The heart of the new transformer is a formed core consisting of nests of laminations of fabricated steel strips. The nests are fitted together providing 100% interleaving, thus minimizing magnetizing current. And since virtually any size core can be produced from the steel strips—*no tools or dies are needed. RESULT:* the design engineer now for the first time can dictate the physical configuration of a transformer, depending upon the electrical characteristics required.

Consult your Sylvania Special Products representative. Or write: Sylvania Electric Products Inc., Ipswich, Mass.

SYLVANIA

Subsidiary of **GENERAL TELEPHONE & ELECTRONICS**

New and Improved Products . . .

Single-Ended Resistors . . .

A new style has been introduced into this company's line of ceramic jacketed wirewound resistors. In place of the usual double-ended leads, this component now features flexible, insulated leads emanating from one end of the resistor. This style lends itself to greater flexibility when the resistor is mounted to the chassis with brackets. *Ohmite Manufacturing Co., 3625 Howard St., Skokie, Ill.*

Warning Markers . . .

Devised to warn low-flying aircraft against collision with transmission line crossings, these cones made of glass fibers and plastic are kept in constant motion by air currents. A distinct improvement over commonly used spherical markers, the markers, which are 20 inches high by 20 inches in diameter, may be readily suspended from crossing wires by split bolt type hangers. *Pacific Float Co., P. O. Box 78, Dillard, Oreg.*

Magnetic Tape Cleaner . . .

Users of magnetic tapes have found that static electricity often causes the accumulation of dirt which can distort information and cause excessive wear to recording heads. With this latest machine, the painstaking hand sponging operation now used can be done automatically. Once the tape is in place and the nonflammable solvent tank loaded, dirt, lint, oil, and fingerprints are removed without disturbing the data contained in the tape. Cleaners are available for ¾-, 1-, and 2-inch tapes. *Computer Measurements Co., 12970 Bradley Ave., Sylmar, Calif.*

Armor Cable Fitting . . .

Series *800* fittings will not only terminate but will also support, ground, mount, and dead end a cable. They are available in four basic pipe diameters, covering the entire range of interlocked armor cable sizes. Eight different fittings are available in each size, for applications ranging from simple armor clamps to compound-filled terminations that can be used in any position. *G & W Electric Specialty Co., 3500 W. 127th St., Blue Island, Ill.*

Telephone Circuit Tester . . .

Where it usually requires 6 minutes to examine 1 telephone circuit by manual methods, the Swept-Band transmission measuring instrument will test 14 circuits in the same time period. Not only does the device indicate any defects in the circuit, but in some cases it will determine the type of defect and its location. Analysis is made visually on a cathode ray display tube. *Siegler Corp., Hallomore Electronics Div., Anaheim, Calif.*

Continuity Tester . . .

Growing out of the need for a device to verify wiring locations in digital computers, the NIFTE or neon indication flashing test equipment will verify complex electronic equipment wiring in about 7% the time usually required for this operation. Requiring no programming or special skills, the instrument can be used to verify over 18,000 circuits in telephone centrals, computers, missiles, aircraft, cable harness, and similar applications. *Autonetics, 91 E. Imperial Hwy., Downey, Calif.*

Machine Tool Sensor . . .

Damage resulting from oversized workpieces in automatic or standard machine tools is prevented with this latest sensing device. The attachment consists of a meter relay where an adjustable pointer is set for maximum allowable cutter overload. A second pointer indicates the actual load resulting from stock on the blank. If the load equals or exceeds the preset limit, the device automatically interrupts the cutting cycle. *Michigan Tool Co., 7171 E. McNichols Rd., Detroit 12, Mich.*

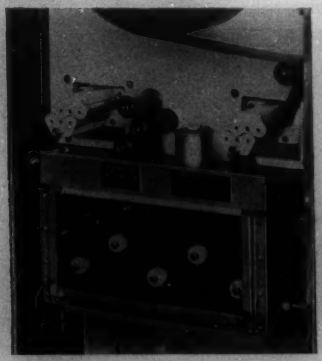
New Motor Line . . .

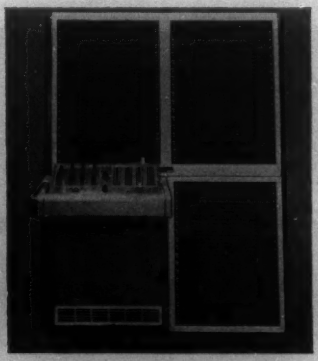
Introduction of a completely new line of fractional horsepower a-c motors will comprise eight ratings from 1/20 to ¾ hp. Capacitor-start, split-phase, and polyphase types will be available in frame sizes 48 and 56, while repulsion-start induction run models will be marketed in frame size 56. Either ball or sleeve bearings can be specified. *Reliance Electric and Engineering Co., 24701 Euclid Ave., Cleveland 17, Ohio.*

Bearing Analyzer . . .

This all-electronic instrument analyzes ball and roller bearings for serviceability. Model *BA 20-2* bases its tests upon vibrations produced by the rotating bearing. Results are presented visually, by means of a meter, a cathode ray display tube, and by a loudspeaker. Normal operation allows a complete nondestructive check of a bearing's surface condition and cleanliness in less than 30 seconds. *Bearing Inspection, Inc., 3311 East Gage Ave., Huntington Park, Calif.*

(Continued on page 15A)





New & Improved Products

(Continued from page 8A)

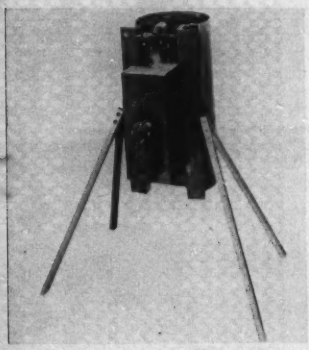
Dictation Machine . . .

A fully transistorized machine that features an endless magnetic belt, reusable many times over, marks the entry of this company into the dicta-

tion equipment industry. Called the Executary, the unit permits 14 minutes of dictation per belt, unlimited review in measured sequences, instant scanning, warning non-belt buzzer, volume indicator light, dual-purpose soundhead with built-in erase circuit, and many other useful operating attachments. *International Business Machines Corp., 549 Madison Ave., New York 22, N.Y.*

Thermoelectric Power . . .

Developed for the U. S. Coast Guard to power land-based navigation aids and off-shore buoy lights, these thermoelectric generators will provide 5 watts of power using only $15 worth of propane. By converting the heat generated by the burning gas directly into electricity through semiconductor



thermopiles, the need for batteries and subsequent maintenance and recharging will be eliminated. The experimental unit shown here on a test stand is 20 inches high and weighs 20 pounds. *General Instrument Corp., 892 Newark Ave., Elizabeth, N.J.*

(Continued on page 20A)

1000*

1000* — *that's the number of Motor Control Center structures* Nelson has supplied to a single industry in just the last 5 years.

What better evidence of complete satisfaction could be desired? Nelson equipment is designed for complete dependability, easy installation, *and* is priced right.

This record of proven performance again confirms the fact that Nelson is

BIG ENOUGH TO PERFORM
SMALL ENOUGH TO CARE

Be sure to let your Nelson representative figure your next job. You will find him listed in the Yellow Pages of major city telephone directories.

If *quick shipment* on Motor Control Centers is of importance to you, ask for a copy of Nelson's new *QUICK-TROL* Bulletin.

** *Ask your Nelson man for the name of the industry and the facts.*

NELSON *Electric* MANUFACTURING CO.
TULSA, OKLAHOMA
P. O. BOX 5385 · NAtional 7-5530

A HISTORIC TELEPHONE EXPERIMENT BEGINS IN AN ILLINOIS TOWN

New technology brings the dream of an electronic central office to reality . . . foreshadows new kinds of telephone service.

Today, the science of communications reaches dramatically into space, bouncing messages off satellites. But an equally exciting frontier lies closer to home. Bell Telephone Laboratories engineers have created a revolutionary new central office. At Morris, Illinois, an experimental model of it has been linked to the Bell System communications network and is being tried out in actual service with a small group of customers.

This is a special electronic central office which does not depend on mechanical relays or electromagnets. A photographic plate is its permanent memory. Its "scratch pad," or temporary memory, is a barrier grid storage tube. Gas-filled tubes make all connections. Transistor circuits provide the logic.

The new central office is versatile, fast and compact. Because it can store and use enormous amounts of information, it makes possible new kinds of services that will be explored in Morris. For example, some day it may be feasible for you to ring other extensions in your home . . . to dial people you frequently call merely by dialing two digits . . . to have your calls transferred to a friend's house where you are spending the evening . . . to have other numbers called in sequence when a particular phone is busy.

The idea behind the new central office was understood 20 years ago, but first Bell Laboratories engineers had to create new technology and devices to bring it into being. A Bell Laboratories invention, the transistor, is indispensable to its economy and reliability.

This new experiment in switching technology is another example of how Bell Telephone Laboratories works to improve your Bell communications services.

BELL TELEPHONE LABORATORIES
World center of communications research and development

Part of a memory plate of the new electronic central office is shown at right (enlarged 8 times). Spots are coded instructions which guide the system in handling calls and keeping itself in top operating form. Over two million spots are required. Logic and memory are physically separated in the machine, so new functions can be easily added. The experiment is being conducted in co-operation with the Illinois Bell Telephone Company and the Western Electric Company.

NOMINAL WEIGHTS OF FINISHED WEATHER-RESISTANT WIRE AND CABLE

(Pounds per 1000 Feet)

Conductor Size AWG or Mcm	Copper & Copper Alloy Conductors				Aluminum Conductors	
	URC Type Double Braid	URC Type Triple Braid	Neoprene Type	Polyethylene Type	Neoprene Type	Polyethylene Type
Stranded						
2	246	270	248	**230**	105	**87.4**
1	155	170	163	**143**	73.3	**53.3**
0	103	115	108	**91.5**	51.5	**35.0**
Solid						
2	239	260	232	**219**	92.2	**79.2**
1	151	164	152	**136**	64.0	**48.0**
0	100	112	101	**87**	45.7	**31.7**

Sources: American Standards Association Specifications

This table shows

POLYETHYLENE covered line wire weighs less

Because it's the lightest, polyethylene-covered line wire is the easiest for linemen to string up . . . hardest for ice and snow loading, gale-force winds to bring down.

Polyethylene-covered line wire, depending on size and conductor, weighs from 5% to 32% less than other types. That's what the figures in the specifications tabulated above show.

This, of course, is no news to linemen who have strung all types of weatherproof line wire. They may not be able to quote pounds and percentages, but they all know you can't beat polyethylene on weight.

Linemen's Favorite Material

Light weight means easy handling, one of the main reasons polyethylene rates tops with installation crews. They also like polyethylene wire because it's clean . . . free-stripping . . . has a smooth, self-lubricating surface that almost makes pulling a pleasure. And despite the exterior slip, the plastic covering hugs the conductor tightly, doesn't ruffle as it goes over crossarms.

"Built-in" Safety Factor

Polyethylene's lightness provides lasting mechanical advantages, since span loads don't tax supports as much as heavier type wire. This "built-in" weight safety factor pays off when violent storms push aerial construction to strain limits . . . when ice and snow loads topple heavier lines.

An added factor in polyethylene wire's ability to stay up under adverse conditions is its smaller diameter. It offers less resistance to wind, a smaller surface for ice build-up.

Winning Combination

Called the "closest to the ideal covering for line wire," polyethylene is outstanding in other respects too. The shield it forms over wire is continuous . . . tough . . . resistant to aging, weathering, moisture, abrasion by lashing branches. It's good for decades of superior service marked by fewer outages, minimum maintenance.

When you order covered wire and cable, make sure the coating is made with PETROTHENE® polyethylene resins. PETROTHENE polyethylene costs no more, but it gives you premium weather and stress-crack resistance.

Polyethylene's advantages are outlined in an informative new U.S.I. data sheet, "Polyethylene . . . The Best Line Wire Covering." Also available is a data sheet showing properties, applications and specifications of PETROTHENE polyethylene compounds. Send for your copies today.

U. S. Industrial Chemicals Co.
Division of National Distillers and Chemical Corp.
99 Park Ave., New York 16, N. Y.

Please send me:
- ☐ "Polyethylene . . . The Best Line Wire Covering"
- ☐ "PETROTHENE Resins for the Wire and Cable Industry"

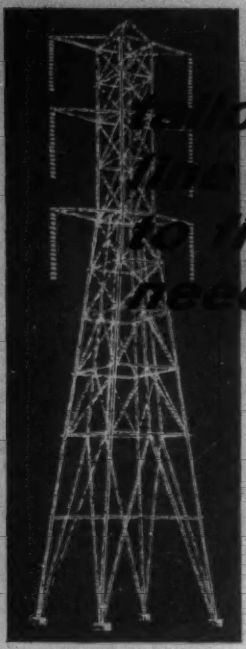
Name:_____ Title:_____

Company:_____

Address:_____

City:_____ State:_____

U.S.I. INDUSTRIAL CHEMICALS CO.
Division of National Distillers and Chemical Corp.
99 Park Ave., New York, 16, N. Y.
Branches in principal cities

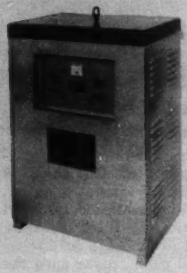


tailor line power to fit your needs

GLENN PACIFIC
INDUSTRIAL POWER SUPPLIES

HERE'S HOW... with a GLENN PACIFIC power supply, you can convert your existing single, two or three-phase ac line power into:

- Any desired voltage—fixed or continuously variable.
- AC or dc output.
- Any volt-ampere curve characteristic—constant current, constant voltage, or reactive to any degree you want.



LINE COMPENSATION VOLTAGE REGULATOR for radar station accepts 3-phase, 208v ±10%, delivers 3-phase 208v ±1% at 300 amp., with non-distorted sine wave at all settings. Rated at 108 kw, 100% duty cycle, convection cooled.

ELECTROLYTIC CAPACITOR FORMING power supply provides continuously-variable dc output from 0 to 415 volts, 300 amperes. Input is 230/460 v 3 phase. Other units available with 0-250 v output. Many of these GLENN PACIFIC units are used by leading capacitor manufacturers.

VARIABLE VOLTAGE transformer used in laboratory power supply delivers 0 to 460 v ac at 200 amperes; operates from 3 phase 208/230 v input.

WHAT'S YOUR PROBLEM? Need a dc source for motor drive and speed control—for powering laboratory or production line dc magnets, instruments, test stands—for electroplating, electrolytic refining, etching, de-tinning? You'll be hours and dollars ahead to contact GLENN PACIFIC; please address Dept. 135.

GLENN PACIFIC CORPORATION
INDUSTRIAL POWER SUPPLIES
703 - 37th AVENUE • OAKLAND 1, CALIFORNIA

EASTERN OFFICE
221 Dukes Road Rahway, New Jersey

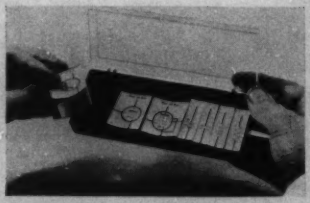
MID-WESTERN OFFICE
640 South York Elmhurst, Illinois

New & Improved Products

(Continued from page 15A)

Drafting Shortcut . . .

A substantial amount of time now spent in drafting complicated electronic circuit diagrams can be saved by using these preprinted symbols. Each component is printed on a self-



adhering matte acetate sheet that requires no cutting or trimming. Available in pads of 100 standardized symbols, these co-ordinated Select-A-Circuit assortments are individually boxed to permit quick attachment to the drawing. *Engineering and Science Aids Co., 392 Jackson Ave., Jersey City 5, N.J.*

Synchro-Verifier . . .

Used to verify the condition of synchronism between two system voltages, this new synchro-verifier relay will provide an adjustable contact closing zone ranging between ±20 and 60 degree phase angle difference between the two. The type *CVE* relay is connected to the two single-phase voltage sources on either side of an open cir-

cuit breaker. When they are in synchronism and equal in voltage, the relay contacts close to permit the circuit breaker to close and connect the two sources. *Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.*

(Continued on page 30A)

Aerospace Problems

SINCE the advent of Sputniks I and II, the barriers of outer space have been probed at an ever accelerating pace. In the conquest of outer space, many disciplines are involved such as Basic Science, Astronomy, Metallurgy, Transmission and Distribution, Electric Insulation and Nucleonics, Radio and Communication Systems, Solid State Devices, Nucleonic and Radiation Instrumentation. Instrumentation, material characteristics, accuracy, and capability of predictable control must achieve new levels to permit man to travel in outer space. Aerospace electricity and its related applications are receiving more emphasis and stature within the Institute and it is expected that this trend will increase. To keep all electrical engineers informed on the most up-to-date electrical engineering problems in outer space, the Aero-Space Transportation Committee has arranged a selection of papers for this special issue, "Electrical Frontiers of Space," of *Electrical Engineering*.

For an over-all picture of the problems yet to be solved for space flight, as well as what has been done, the advantages to be gained, and the possible role of electricity in the propulsion problem, a challenge to electrical engineers is presented in the lead article, "An Engineer Looks at Space Flight," by a noted authority. To meet this challenge, engineers have turned toward direct conversion to electricity, and six of the articles which follow present the present state of the art in respect to thermoelectric, magnetohydrodynamic, and thermionic conversion. Other papers treat environmental effects, electric systems, communications, transients, grounding, radiation, and radio-frequency shielding.

Steinmetz's findings on power generation, the Seebeck laws, Curie point, and cryogenics, as examples, have taken on meanings other than laboratory curiosities when the space environment is considered. Exposures to nuclear bombardment, Van Allen belt, simultaneous solar heat and cold, and lack of atmosphere present unlimited challenges. The demand for resolution of problems to permit transcending the confines of the earth environment will have revolutionary effects on many of our currently accepted systems and practices. Just as many of Jules Verne's predictions require updating as a result of the 1960 *Nautilus* performances, so will space considerations affect the standard literature on electrical phenomena of the future. The strides from DeForest, to transistors, to molecular electronics are remarkable. Other phases of electrical science are progressing just as rapidly.

The problem areas today include all aerospace vehicles and their supporting systems and equipment. The Aero-Space Transportation Conference held in San Diego, Calif., August 9-12, 1960, indicated that a greater effort was being expended on basic scientific investigation of the space environment and its effect on materials, performance, and established concepts. The increased emphasis throughout the nation on weapons systems and space research has accelerated electrical developments, which should be reported at technical conferences and published in the journals. This increased emphasis on space problems is continuing as plans develop for the 1961 Aero-Space Transportation Conference.

Timely attempts to solve many of these complex problems appear on the following pages.

An Engineer Looks at Space Flight

K. J. BOSSART

A brief description of space flight is presented from the perspective of the engineering disciplines. Main benefit accruing to mankind will be in the qualitative leap in scientific knowledge.

THE evolution of technology is proceeding at an ever-accelerating pace. In the short span of one generation we have witnessed the advent of radar, the gas turbine, supersonic flight, nuclear and thermonuclear energy, television, electronic computers, isotope tracers, semiconductor applications, etc. . . . and now space flight.

The ultimate impact of these various new technologies upon our daily lives—economically, sociologically—is difficult to evaluate. Comparing them from a strictly utilitarian viewpoint, we must conclude that space flight does not rank with the great emancipators as far as immediate material benefits go. Astronautics is not a great purveyor of wealth, nor a great eliminator of drudgery. Undeniably, the orbiting satellite has several practical applications, but the more important return from space-flight investment will be of an indirect or intangible nature. We in the United States have already reaped a very real benefit from the onset of space flight. I am referring to the rude awakening of public opinion 3 years ago at the launching of Sputnik I—an awakening to the fact that support of scientific endeavor in this country is not what it might be.

Because space flight involves primarily a technical effort, we engineers by professional training may be inclined to evaluate the end results in terms of material benefits only. Certainly the extension of man's activities beyond the bounds of this planet merits a much broader appraisal. Let us remember that material gain is not the only motivation that makes the world go 'round. The spirit of adventure, the thirst for knowledge made man what he is today. Thank God, the compulsion to meet a challenge still lives within us. Throughout man's history the conquest of environment and the pushing back of frontiers have been ever-recurring challenges. Space flight involves both.

As we enter the fourth year of the space age, we can say without fear of contradiction that the United States has been equal to the challenge of space. We have launched some 30 spacecraft of various descriptions—Vanguards, Explorers, Pioneers, Discoverers, etc. Our harvest in new information about interplanetary space has been rich and varied. Tiros is opening new vistas in meteorology. Echo and Courier show the way to much needed new communication channels. Midas and Samos give promise of great military value. Discoverer is teaching us how to return from outer space.

And this is only a beginning. The National Aeronautics and Space Administration (NASA) was organized under the able leadership of Dr. Keith Glennan to spearhead our space effort. Last July Dr. Glennan gave us a preview of things to come. The goals he has set for NASA in the next decade are indeed impressive. The soaring sixties will witness in succession manned orbital flight in Project Mercury, hard landing of an instrument package on the moon, instrumented probes reaching the vicinity of Venus and Mars, unmanned controlled landing on the moon, an astronomical laboratory in orbit, an orbiting manned space station leading to manned flight around the moon. Manned landing on the moon is anticipated in the seventies.

To accomplish these feats, more powerful rocket boosters are now being designed and built: the Centaur, the giant Saturn, and, further along the road, nuclear-propulsion test vehicles. No less than 260 launchings are contemplated for this decade, about half of which are intended for scientific missions.

The cost of these activities is estimated at $15 billion. Exploration of space does not come cheap. Unlike the airplane, no spacecraft will originate in a bicycle shop. In fact, space may well remain outside the realm of private enterprise by virtue of the tremendous initial investment required. The current cost of sending a payload into even a low-altitude orbit ranges around $500 per pound. For interplanetary trips this figure can go up by orders of magnitude. Here then, without a doubt, lies the greatest obstacle to space travel. To bring down these costs is a great challenge to the space engineer.

SPACE FLIGHT IS MAINLY ENGINEERING DISCIPLINE

SOME TECHNOLOGIES found their origin in newly discovered phenomena in physics. Typical examples are radio, which resulted from the discovery of electromagnetic wave propagation, and atomic energy, which followed our understanding of the nature of the atom's nucleus. Not so for space flight. The basic principles involved—namely, the laws of gravitation and conservation of momentum—have been well understood since Newton's days. Knowledge of the jet propulsion principle dates from antiquity. It is entirely a matter, then, of developing systems that will make use of such fundamentals in the most efficient way—definitely an engineering job.

This is not to say that it is an easy job. It covers a gamut of disciplines which is extremely broad, ranging from chemistry to electronics, from metallurgy to nucleonics, from ecology to astronomy. Even though we

A special article recommended for publication by the AIEE Aero-Space Transportation Committee.

K. J. Bossart is with Convair Astronautics, a division of the General Dynamics Corporation, San Diego, Calif.

may be familiar with the basic principles, a lot of new knowledge will have to be acquired in specific fields. A case in point is knowledge of environmental conditions to be encountered in space. It is not by coincidence that half of NASA's scheduled launchings are aimed at acquiring such information.

As always in marginal undertakings, even small improvements in design are rewarded by very large increases of performance. And, as of today, interplanetary flight is indeed a marginal affair. Grappling with the gravitational field of the sun is no easy assignment. So far we can only do it in a very limited way by resorting to trickery in the choice of our flight path. This means that a flight to Mars or Venus is only possible when these planets are in the right location with respect to the earth—a happenstance which occurs about half a dozen times in a decade. Even with this limited capability the operation is so marginal that a loss of 1 or 2% in propulsive efficiency might easily result in cutting the payload in half.

In the battle for efficiency, the most rewarding field is to be found in the propulsion system. The law of conservation of momentum decrees that the only way to impart momentum to an object is to impart an equal and opposite momentum to some other mass. While on earth, this "other" mass is generally supplied by the environment—water, air, or the earth itself. In the emptiness of space, this mass can only come from within the vehicle itself. It is the mass of what the rocketeer calls the propellant—fuel and oxidant in the case of the chemical rocket. In today's rocket technology, this mass is the lion's share of the total launching mass of the spaceship. Even for the most moderate space mission it amounts to many times the mass of the payload.

TRADING MASS FOR ENERGY

How can we combat this handicap? Obviously, we can increase the momentum obtained from the ejection of a given mass m by increasing the ejection speed. Or, conversely, we need only half the m to produce a given mv if we double the velocity v. This means, however, that the kinetic energy $\frac{1}{2}m.v^2$ is also doubled. In other words, we have traded mass for energy. The more energy we can pack into a unit mass of ejected propellant, the less mass we will need.

In the case of the chemical rocket, this energy is obviously limited by the heat content of the reacting chemicals. Today we have just about reached the ultimate limit in the kinetic energy that can be extracted from a pound of chemical propellant. There are, however, other means of energizing our propellants. And thanks to the advent of the atomic reactor, energy may be easier to come by in space than mass. Kilowatt-hours may be more available than pounds.

By simply heating a low-molecular-weight propellant —such as hydrogen—in a reactor, the nuclear rocket can achieve exhaust velocities of some 25,000 feet per second, or about double the best that can be done chemically. We can be sure that once the many problems of the nuclear rocket are licked, space flight will enter a new era.

The abundance of energy in space may sometime open another intriguing possibility. The most demanding part of an interplanetary trip is lifting the propellant mass out of the grasp of the gravitation of the earth or any other planet. The job would be ever so much easier if propellants could be taken aboard in a low-gravity environment. The thought therefore occurs that if adequate power could be installed on a low-gravity body such as the moon or a satellite of Mars, this power could be utilized to manufacture propellants on the spot. Whether such a scheme ever will be practical only the future will tell.

In order to transfer heat from a nuclear reactor to a propellant, the temperature of the former must of necessity be higher than that of the latter. We see then that the energy level in the exhaust of a nuclear rocket is limited by the metallurgy of the reactor. To get still more energetic exhaust we have to look for forms of energy other than heat. Here electricity comes to the rescue. By accelerating charged particles—such as ions—in electrostatic and/or magnetic fields, exhaust velocities of hundreds of thousands of feet per second are theoretically possible.

With this kind of velocity the propellant load is no longer the major burden of the spaceship. This dubious distinction now shifts to the propulsion system itself. Unfortunately, the weight of the electrical propulsion system comes very high. It has to include the nuclear reactor—the prime source of energy—and also the turbogenerator with all the necessary accessories, not the least of which is the radiator required to dissipate waste heat. This amounts to thousands of times the thrust produced. By comparison the weight of a chemical rocket engine is less than 2% of the thrust. This low thrust-to-weight ratio obviously precludes take-off from the earth on electrical power. Electrical propulsion can only be useful when starting from a satellite orbit and then days and weeks will be required to accelerate the space vehicle to the required velocities.

Notwithstanding these serious drawbacks, electrical propulsion appears to have good potentialities for interplanetary missions. The imaginative electrical engineer is presented here with a fertile field. Getting the weight down is only one of several problems to tackle. Ten pounds per kilowatt is a good goal to shoot for right now. Maybe we can even hope for an efficient direct conversion generator, be it thermoelectric, thermionic, or magnetohydrodynamic.

While propulsion offers much challenge to the engineer, it is only one of many facets requiring attention. In airborne transportation the cost per ton-mile has come down two orders of magnitude since the Wright brothers' experiments. A similar increase in efficiency should be possible in space. The use of recoverable boosters alone would go a long way toward accomplishing this goal.

Many other problems are begging for improved solutions. In fact, some of them we may not even suspect. A

pertinent example is the problem of radiation in space. The existence of regions of intense corpuscular radiation was a startling revelation resulting from our early probings into the space domain. Only recently have we become aware that the radiation in these so-called Van Allen belts is child's play compared to that brought about by solar flares. It is clear that phenomena such as these will present a formidable obstacle to manned interplanetary travel. Even without this additional stumbling block the problems of long duration reliability, life support, psychological aspects, atmospheric re-entry, etc., will make a manned expedition many times more difficult than one carrying inanimate payloads only.

BENEFITS OF SPACE FLIGHT

LET US COME BACK NOW to the question of the benefits of space flight. Do the results justify the expenditure involved? In the case of "near space" the answer is an unqualified "yes." The arts of weather prediction, geodesy, communication and reconnaissance stand to benefit immeasurably from the man-made satellite. I take a dim view, however, of the use of weightlessness in orbit for novel industrial processes or medical treatments. The cost is simply too high.

Disregarding the philosophical considerations mentioned previously, the answer is not so clear cut in the case of "deep space." Can we relieve the population pressure on earth by colonizing the near planets? In my opinion the idea is preposterous. It is difficult to imagine an environment more hostile to man than that existing on our sister planets. A technology capable of coping with such environment—capable of supplying water and oxygen on the surface of Mars, let us say—would be ever so much more adequate for creating living space on our deserts, oceans or even polar caps.

Some space enthusiasts suggest that a more hospitable climate might be found on planets of other stars. Maybe so. But assuming we are able to establish the fact that there are such worlds within our capability of reaching them, the travel time required to get there would be measured in centuries or milleniums.

The possibility of exploiting the mineral resources of near planets is occasionally suggested. Even forgetting the difficulty of prospecting on a planet devoid of air, the cost of bringing back even the most valuable minerals would exceed the cost of processing the poorest ores here on earth.

When all is said and done, three potential benefits of space exploration remain, any one of which may justify the effort expended. The first is a fringe benefit, a by-product of space technology. I am referring to the technological advances that will result from the quest for more efficient space flight. A typical example would be the generation of electricity by direct conversion of atomic or heat energy. If the pressure for efficiency in space brings about or accelerates such a development, it will have paid for itself.

Secondly, we have the enhancement of national prestige. This is not an engineering consideration, but in the present world political climate its value should not be underestimated.

Finally, and potentially most important, there is the acquisition of human resources. Not mineral resources, not real estate, but the very essential resource of scientific knowledge. Even before man was able to send his instruments into space, he gleaned some fundamental information from the heavens. Newton deduced the law of universal gravitation from the motion of the planets. Einstein verified the theory of relativity by looking at the stars. Thanks to space flight, our astrophysicists will be able to study nuclear processes in the stars without the impediment of an interposed atmosphere. Talking about "Innovation in Physics," Dr. Freeman Dyson of Princeton's Institute of Advanced Study, writing in the *Scientific American*, estimates that ". . . the next important innovation will arise out of gravitational or astronomical observations made possible by elaborate equipment assembled in interplanetary space."

Turbines for 80-Knot Hydrofoil Boat

Two seagoing small gas turbines built by The Garrett Corporation's AiResearch Manufacturing Division, Phoenix, Ariz., will start and supply electricity for a powerful new hydrofoil boat.

The 104-foot-long craft, capable of 80-knots on the open seas, is being built for U. S. Maritime Administration by Grumman Aircraft's Dynamic Developments.

Scheduled for launching early next spring, the 80-ton all-aluminum hydrofoil craft will use two AiResearch *GTCP 85-91* turbines equipped with special, light aluminum housings. These turbine units will pneumatically start the aircraft-type turbine prime mover which skims the craft through the water on two sets of foils.

Once their task of spinning the main jet power plant to life is completed, the AiResearch turbines will turn to the task of generating all electric power needed to operate the boat.

Based on Grumman's experience as the largest builder of amphibious aircraft, the boat relies extensively on aircraft-type construction. In operation, a set of foils in the water just forward of the craft's center of gravity will "fly" the boat hull above the water. Another set of smaller water-foils well aft provide excellent stability and high-speed maneuverability. The new development is a historical repeat, since AiResearch developed the first successful small gas turbine in 1946 for use on U.S. Navy aircraft "flying boats."

Thermoelectricity Application Considerations

A. A. SORENSEN
MEMBER AIEE

Compared to other energy conversion devices, the thermopile is simple in construction, static, operable from several types of heat sources, and adaptable to various ambient conditions. Some design considerations for space, terrestrial, and marine applications are presented.

THESE DAYS a designer is faced with a multitude of electric power requirements—from milliwatts to megawatts—defined by new weapon and space systems concepts. At his disposal, fortunately, is a wide variety of potential sources of electricity. There is renewed interest and activity in fuel cells and thermionic and thermoelectric converters, for example. These, together with improved batteries and rotating generators driven by a wide range of prime movers, offer a wealth of possibilities to be studied for a given system. The particular selection, of course, is governed by an optimization study, taking account of required power level, mission time, and desired characteristics.

The thermopile is a contender for many applications, now that solid-state physics studies have brought about more efficient and uniform thermoelectric materials. It has both advantages and disadvantages. Compared to other energy conversion devices it is simple in construction, there being no electrical fluids or extremely close spacing to maintain. Being static, the thermopile has the possibility of long life. It operates from chemical, solar, or nuclear heat sources, is able to use waste heat, and adapts to various ambient conditions. On the other hand, its specific weight is still high, voltage is low, and time constants are long.

Even so, electromagnetic machines also generate low voltage from the standpoint of individual turns. Similarly, in a thermopile, series connections are necessary to obtain required voltages. Power transistors and other solid-state devices are now used in efficiently converting direct current to the desired utilization levels and frequencies. Using a storage device, we can handle long time constants more easily with direct current than with alternating current sources.

ENGINEERING DESIGN

THE USE of stable metals or alloys for thermocouples in measurement and control applications has grown into an important technology. Semiconductors also have long been recognized as powerful thermoelectric materials. Although only a few semiconductors are elemental in composition, there are numerous semiconducting compounds, many of which will give an electrical output when subjected to a temperature gradient. Some of these are particularly interesting because, having low thermal conductivity, they are economical in their use of heat. General requirements for these materials for practical use in generators are: high electrical output, low thermal conductivity, stability, and adaptability to production processes.

An important phase in the materials program for any semiconductor is the control of the electron or hole concentration in the crystal. In elementary semiconductors, such as those used in diodes and transistors, this is accomplished by adding the desired impurity atoms which introduce donor or acceptor levels in the band structure of the semiconductor. The situation is more complicated in binary compound semiconductors because the dominating carrier type is influenced by the deviation of the compound's composition from stoichiometry. Thus, the material's properties are influenced

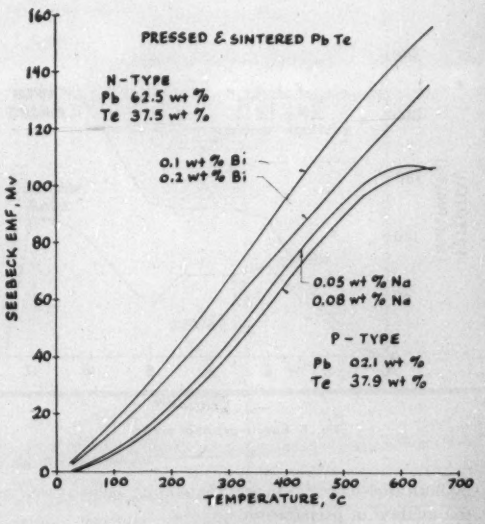


Fig. 1. Seebeck emf vs. temperature.

Full text of conference paper CP60-1066, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

A. A. Sorensen is with The Martin Company, Baltimore, Md.

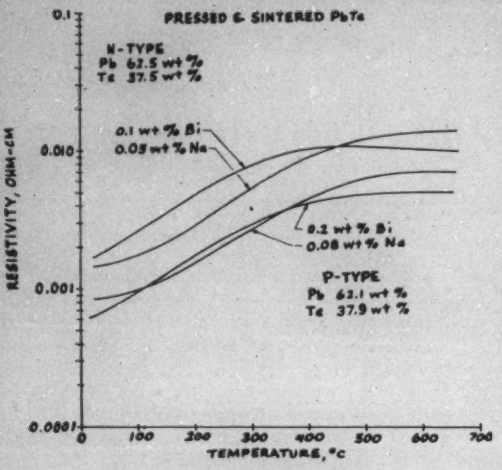


Fig. 2. Resistivity vs. temperature.

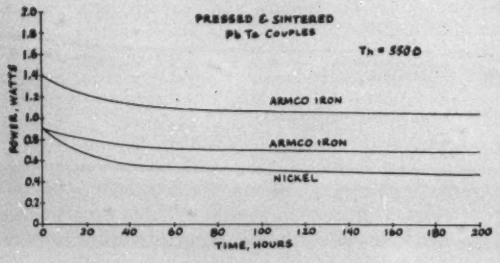


Fig. 3. Power output vs. time.

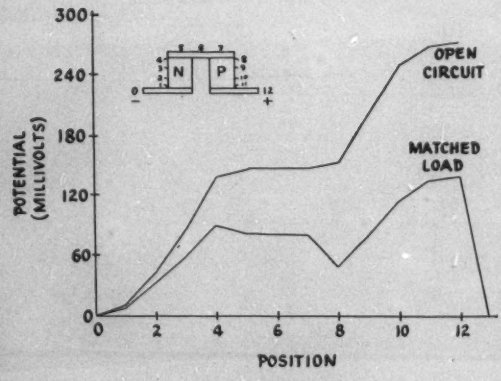


Fig. 4. Couple potential profile.

by both the composition and the doping agent as well as the method of preparation.

One example of such a thermoelectric material is lead telluride. Couples of the highest efficiency are obtained if the n-type material is prepared with excess lead over the stoichiometric ratio and p-type material is prepared with excess tellurium. However, the material with excess lead is mechanically superior to the excess tellurium material and lends itself better to the mechanical processes necessary in the construction of a generator.

The method of preparation also affects the mechanical characteristics. For example, pressed and sintered lead telluride is machined more readily than cast material. Pressing and sintering methods also lend themselves to the preparation of graded thermoelectric arms; that is, greater doping of the hot end of the arm than the cold end. These methods are used because of the temperature dependence of the material's properties and result in some increase in efficiency. Typical characteristics of graded n- and p-type arms produced by the pressing and sintering method are shown in Figs. 1 and 2.

In engineering applications, more than optimum n- and p-type thermoelectric arms are required, however. Also required are a heat source, electrical insulation for the hot and cold sides of the couples, thermal insulation, electrical connectors for the hot and cold sides of the arms, and a heat sink. As far as the heat source and sink are concerned, the problem in engineering design is to match available heat fluxes with those required for the thermoelectric elements. Probably the most troublesome item is joining the electrical connections to the thermoelectric arms. Soldering is generally adequate for the cold sides, but for the hot sides materials must be used which do not affect the performance of either the n- or the p-type arms. Fig. 3 shows the output of three couples made with lead telluride, two with iron electrodes, and one with nickel. The drop-off in output with time is more rapid for the nickel electrode due to the hot end of the p-type material changing to n-type.

A useful tool for gauging over-all performance of a thermocouple is the couple potential profile shown in Fig. 4. Fine-wire voltage pickups are attached at points on the thermocouple as indicated by the numbers shown. Voltages across the cold end connections are indicated by 0 to 1 and 11 to 12 and voltages across the hot end connections by 4 to 5 and 7 to 8. The open-circuit profile of the couple shows the voltage distribution between the n- and the p-type arms. This will also show up deterioration in performance during extended operation and point to the cause of the difficulty, such as reverse doping of an arm by the electrode. In this case, a reverse voltage is seen at the hot end of the arm involved. The matched-load profile permits a determination of the contact resistances under operating conditions and shows the output distribution between the two arms. The profile also allows voltage drop in the body of the electrode connecting the two arms to be checked.

The hot connecting electrode can become an appreciable weight item, particularly when contact resistance is lowered and the element lengths decreased. Fig. 5 shows resistance vs. temperature for some of the metals of interest for contacts. At higher temperatures, compos-

Table I. Space Applications

Applications	Ratings	Limitations
Electric power source for rocket stages, using cryogenic cooling and rocket heat	1 to 20 kw (15 to 25% efficiency)	Weight, thermal log
Electric power source for satellites, using nuclear or solar heat sources	1 watt to 5 kw (5 to 8% efficiency)	Pumping losses limit efficiency in intermediate ratings. Heat storage needed for solar source
Control power devices	Milliwatts to watts	

Table II. Terrestrial Applications

Applications	Ratings	Limitations
Propulsion for automotive equipment	5 to 10 kw (10% efficiency)	Best suited for low speed, intermittent use. Battery needed for peak loads
Combustion-powered portable electric power source for quiet operation	100 watts to 5 kw (5 to 10% efficiency)	Pumping losses an appreciable part of output
Solar - powered battery chargers for use in remote areas	25 watts to 1 kw (2 to 7% efficiency)	Orientation and concentration required for higher efficiencies

ite connectors are indicated to obtain minimum connector volume.

Efficiency is dependent upon the figure of merit (usually designated by Z)—a composite of the Seebeck coefficient, thermal conductivity, and resistivity. Thus far, the highest figures of merit have been attained by materials suitable for use in the room temperature range. The general trend as temperature increases is shown in Fig. 6. Representative of class A are various alloys of Bi_2Te_3. Class B includes PbTe and InSb, while class C covers oxides and silicides. In design work, the conditions under which operation is to take place must be established—the heat sink temperature, range of temperature from the heat source, required life, and the characteristics required by the load. From the standpoint of the effect upon the thermopile, designs fall into three general categories: space, terrestrial, and marine.

Space. From the design point of view, space is the worst application because radiation is the only heat-dissipating agent available. For small power applications, conduction may be used to transport the heat to the radiator. If the power is appreciable, though, weight becomes excessive for this method and a circulating fluid system must then be used. When a design is optimized for weight by compromising between the weight of the radiator and the weight of the thermopile and heat source, then the radiator operates at a comparatively high temperature. Optimization may be carried out by the analytical solution of equations, by a computer, or by graphical solution based on calculations of several cases, as shown in Fig. 7.

Since the temperature gradient in the elements is assumed to be fixed, the weight of the thermoelectric elements does not change greatly with the radiator temperature. Thus, for a fixed maximum temperature, the greater number of elements required at a higher radiator temperature is compensated by their shorter length. This assumption requires that contact resistance must not be the governing factor in element length. Table I shows some possible space applications.

Terrestrial. Although nuclear, solar, and combustion

Table III. Marine Applications

Applications	Ratings	Limitations
Main propulsion	500 kw and up (15 to 20% efficiency)	
Auxiliary power	250 watts to 100 kw (5 to 20% efficiency)	Best used with battery for system voltage control
Signal devices	5 to 50 watts (10 to 15% efficiency)	

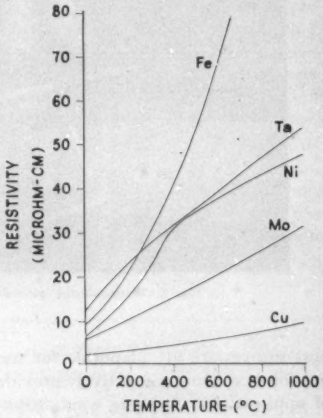


Fig. 5. Resistivity of some metals.

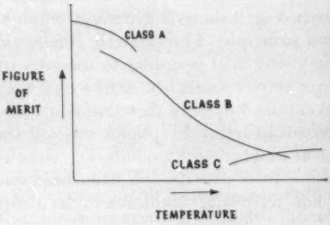


Fig. 6. Figure of merit vs. temperature for typical thermoelectric materials.

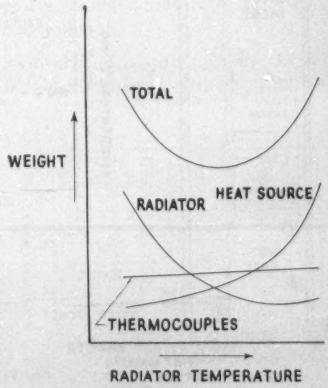


Fig. 7. Graphical solution for minimum weight for heat source, thermocouples, and radiator.

Fig. 8. Thermoelectric generator.

heat sources are all adaptable for terrestrial use, combustion heat sources will likely provide for the majority of applications. Catalytic combustion processes are especially adaptable to thermoelectric generation, since an extended high temperature area can be provided and heat transfer is largely by radiation, thus reducing stack losses. Fig. 8 shows a generator employing this combustion principle. The catalytic combustion tube held by the young man is similar to the ones inside each of the three conversion tubes. At the time the photograph was taken, the output of the generator with pressed and sintered lead telluride couples was 130 watts. Each of the stacks weighed 46¾ pounds. Fig. 9 shows a profile of the temperature distribution from heat source to sink.

For terrestrial applications, as contrasted to space, both radiation and convection effects can be used to dispose of unusable heat; thus, radiator weight can be much lower. However, pumping power is needed to move air through a radiator, and again an optimization must be made between over-all efficiency and weight. Military specifications for ground applications set the maximum cooling-air temperature at 125 F. For airborne applications, temperatures may be lower or higher depending upon the use. Table II demonstrates possible applications.

Marine. Marine applications are the most favorable from a heat disposal viewpoint because water is available in quantity at a temperature no higher than 80 F. Thus, both the machinery for heat disposal and the pumping power requirements are low. Some marine applications are outlined in Table III.

The design of a complete power conversion system not only is governed by the capabilities of thermoelectric materials, but also is strongly influenced by the temperature limitations of the heat source, electrodes, seals, support materials, and electrical and thermal insulation. Although the marine application is the most favorable from the efficiency standpoint, it should not be inferred that it is the only practical one. In each area thermoelectric power systems are subject to the same engineering material limitations as competing systems. In one respect, they have an advantage in not having to withstand the high stresses encountered with rotating systems. The incentive for operation at higher temperatures in space applications will demand extra time and effort in materials development and engineering effort. A projection of near-term thermocouple efficiencies for the three areas is shown in Table IV. Over-all equipment efficiencies will be lower because of the factors previously discussed.

Table IV. Net Thermocouple Efficiency

	Temperature		Efficiency		
Application	T_h	T_c	Eff_c	Eff_{tc}	Eff_N
Space	2,000° F (1,093° C)	900° F (482° C)	45%	17%	7.7%
Terrestrial	1,600° F (871° C)	150° F (66° C)	70%	26%	18%
Marine	1,600° F (871° C)	45° F (7° C)	75%	28%	21%

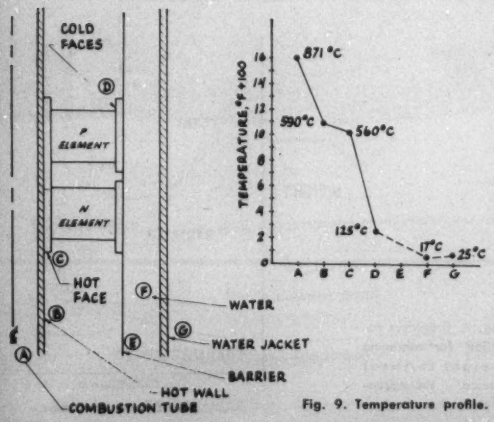


Fig. 9. Temperature profile.

METHODS OF USE

With currently possible efficiencies of about 10%, the value of m (ratio of external to internal resistance) is approximately 1.3. This means that at the maximum efficiency point, the ratio of open-circuit voltage to closed-circuit voltage with rated load is 1.77, or a regulation of 43.5%, which is equivalent to that of an unregulated a-c generator. With improved materials, m will be larger and the regulation lower in value. A plot of voltage, current, and power against per-unit resistive load is shown in Fig. 10. Note that power output is nearly constant over a considerable range of load resistance. Applications requiring a constant power input, such as some motor drives, could take advantage of this charac-

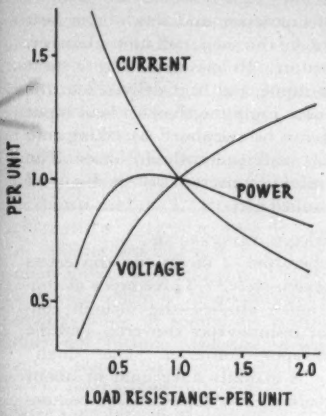
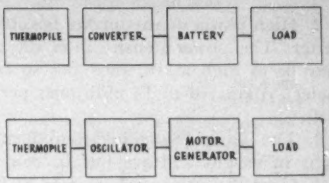


Fig. 10. Output parameters vs. load.

Fig. 11. Arrangements for supplying cyclic loads.



teristic. In other applications needing direct current at various voltages, transistor converters with internal voltage regulators may be used. Similarly, for a-c needs, inverters may be used.

An important use for thermopiles is to supply power continuously to a storage device, such as a battery or rotating flywheel, from which energy is withdrawn as needed. In this application, the thermopile can be operated at its most efficient load. The task of regulating the voltage and converting it to the required form may be left to the intermediate equipment. Two arrangements are shown in Fig. 11.

Each source of electric energy, be it an electromagnetic generator, primary battery, or thermopile, has its distinctive characteristics. In working with these sources, engineers become aware of their limitations and, thus, fit designs to their various characteristics. With the thermopile becoming generally available, engineers will consequently become adept in designing around its limitations and exploiting its advantages.

Experimental Solar Thermionic Converter for Space Use

HENRY OMAN
MEMBER AIEE

GEORGE STREET, JR.

A high-pressure cesium-vapor thermionic converter appears to be a promising source of power for space vehicles. On the basis of an analysis described in this article, it was found that a converter with cathode temperatures of 3,000 to 3,500 degrees Rankine will result in low system weight and high over-all efficiency.

POSSIBLE ENERGY SOURCES for satellites and space vehicles are chemicals, nuclear energy, and solar energy. For long flights, chemical-consuming devices, such as batteries and monopropellant or bipropellant engines, are much heavier than alternative nuclear power sources for large electric loads or solar power sources for small loads. The subject of this article is a promising solar power source, the solar-heated thermionic converter. Basic components of this power source are a mirror or lens for concentrating sunlight, a thermionic converter, and a waste-heat radiator. The thermionic converter appears to have a number of advantages over alternative energy converters for space vehicles. They are as follows:

1. High conversion efficiencies are possible. In the laboratory, 17% has been achieved with a cylindrical converter.

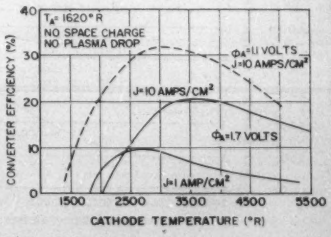


Fig. 1. Effect of cathode temperature on ultimate converter efficiency.

Full text of conference paper CP60-1040, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

Henry Oman is with the Boeing Airplane Company, Seattle, Wash.; George Street, Jr., is with the General Electric Company, Schenectady, N. Y.

2. High power density makes possible a compact converter. The power density in a thermionic converter may be as high as 10 watts per sq cm (square centimeter), compared to 14 milliwatts per sq cm for solar cells.

3. The power-producing components can be made light in weight and are low in cost.

4. Since the converter operates at high source temperatures, a reasonable Carnot efficiency is obtainable with a fairly high waste-heat rejection temperature. This makes possible a small radiator.

5. The thermionic energy conversion process is not affected by Van Allen radiation, as is the photovoltaic process.

The solar-heated thermionic converter also has disadvantages. The major ones appear to be:

1. The high cathode temperature can be achieved only by concentrating sunlight with a precise mirror or lens which must be accurately oriented.

2. Satisfactory methods of mounting and connecting in series a number of thermionic cells in one focal area have not yet been proved.

3. The design of low-heat-loss high-temperature structure for supporting thermionic converter components is not simple.

An experimental program has been initiated to provide quantitative evaluations of the advantages and disadvantages of solar-heated thermionic converters. Analytical work which preceded the design of the experimental earth-test unit will be described here. Experimental results were not available at the time this article was written; however, they may be available at the time it is published.

The design of a solar-heated thermionic power source starts at the thermionic converter. The converter design establishes the temperature and quality of waste heat that must be dissipated, and from this criteria the waste-heat radiator can be designed. The converter design also determines the temperature and flux of the heat that must be delivered by the solar radiation absorber. The absorber temperature is maintained by a heat balance between heat input, and heat delivered to the converter plus heat losses. From the absorber heat input the concentrator area can be calculated by taking into account enclosure loss and concentrator losses. The design of a solar thermionic converter will be discussed in the order just mentioned.

THERMIONIC CONVERTER

THE THEORY and operation of thermionic converters have been described extensively.[1-3] Three types of converters are being seriously studied—the vacuum converter, the low-pressure cesium-vapor converter, and the high-pressure cesium-vapor converter. The "high" cesium-vapor pressure is actually a vacuum of about 2 mm of mercury absolute. The high-pressure cesium-vapor converter design was selected for this experimental program because it shows promise of achieving power densities of the order of 10 watts per sq cm and efficiencies as high as 17%.

The main design variable in a thermionic converter is cathode temperature. The cathode temperature for the experimental unit was selected on the basis of the highest conversion efficiency. Fig. 1 shows the ultimate converter efficiency as a function of cathode temperature for a constant 1,620 R (degrees Rankine) anode temperature. Curves are shown for work functions of 1.1 electron volts and 1.7 electron volts, and current densities of 1 and 10 amperes per sq cm of cathode area. As shown in Fig. 1, the converter efficiency is highest at cathode temperatures in the range of 2,700 to 3,500 R. It drops off at lower cathode temperatures as a result of electron emission limitations. At higher cathode temperatures, the efficiency drops off because of increased heat loss by thermal radiation from cathode to anode.

It is also necessary to examine the ultimate performance of the entire space-vehicle power source when various cathode temperatures are employed, because

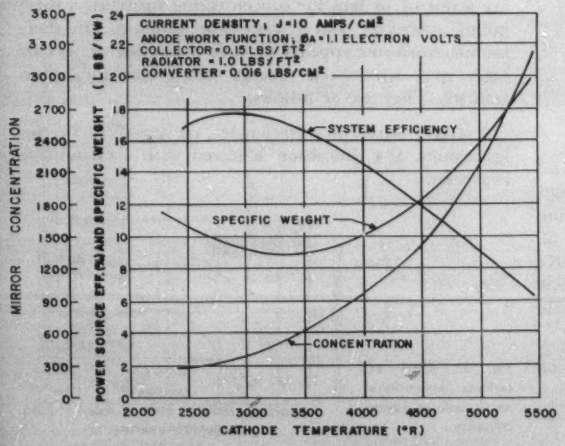
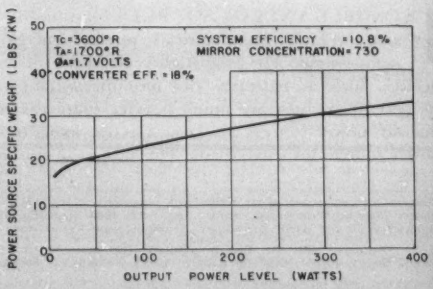


Fig. 2 (left). Effect of cathode temperature on solar thermionic power system parameters.

Fig. 3 (below). Specific weight of thermionic converter with fin-type radiator.



increasing the cathode temperature increases the reradiation loss, and hence necessitates a larger concentrating mirror to collect the required amount of radiation. Such an analysis was made and the results are shown in Fig. 2, where the three major parameters of a solar thermionic power source—specific weight, system efficiency, and required mirror concentration ratio—are plotted as functions of cathode temperature. The curves are based on an optically perfect concentrator, component weights as shown, and the 1.1 electron-volt anode work function curve in Fig. 1. Heat transfer by conduction from anode to radiator was assumed. It will be noted that a minimum specific weight occurs at about 3,400 R, and that a specific weight of 10 pounds per kilowatt is theoretically possible. It should be realized that this weight does not include structure, orientation controls, or energy storage for satellite vehicles.

On the basis of this analysis and demonstrations by laboratory models of thermionic converters, it was concluded that a converter with cathode temperatures in the range of 3,000 to 3,500 R will result in the lowest system weight and highest over-all system efficiency.

Waste Heat Dissipation. A thermionic converter is a heat engine which operates between a source temperature and a sink temperature. Low sink temperature can be maintained only by transferring waste heat away from the anode.

A possible system for dissipating waste heat is one employing an intermediate heat transfer loop. The power level at which the complexity and power loss of an intermediate heat transfer system employing pumps becomes practical has not been determined. At 10 kw and above, the incremental increase in weight attributable to circulation pumps and the auxiliary power to operate them is minor. At a 1-kw power level, it would appear that the extra weight needed for pumping would exceed that necessary for producing output power.

The system best suited for production of power, up to possibly 1 kw, has solid fin-type radiators fabricated directly to the thermionic anodes. Waste heat is conducted from the anode through a metallic path to the radiating surface. This surface can be a disk-type fin oriented to reject approximately one half of the heat to space and the other half into the collector where it is reflected to space. The radiator material should have a high ratio of thermal conductivity to density and adequate strength at its operating temperature.

As the thermionic converter power rating is increased, more radiator material is used only to conduct heat to the radiating surface, hence radiator specific weight increases. Fig. 3 shows the resulting system specific weight for the low-power converter under the ultimate performance conditions noted. The specific-weight value includes only the collector, converter, and radiator components. Again, perfect concentration optics are assumed.

Description of Test Converter. A cross section of the converter radiation design adopted for this experimental investigation is shown in Fig. 4. The major components

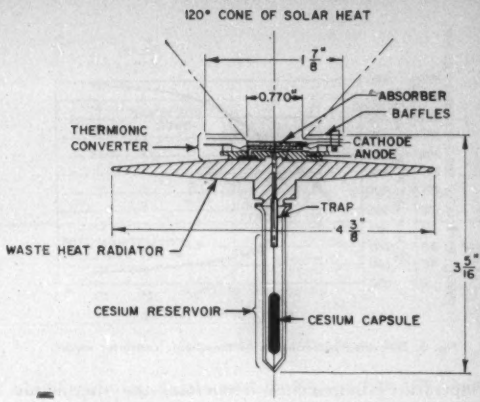


Fig. 4. Cross section of thermionic converter model.

are the thermionic converter, waste heat radiator, and cesium reservoir. The converter will be mounted so that its absorber surface is at the focus of the solar collector and the cesium capsule is pointed away from the collector.

A design cathode temperature of 3,600 R was selected to permit the exploration of the effects of varying this parameter within the range of maximum efficiency. A cathode area of 3 sq cm has been selected for the model because it appears to be the largest practical size that will produce a reasonable amount of power and yet be capable of operation with an available simulated solar source and available solar collectors. The nominal specifications of this converter are shown in Table I. Fig. 5 shows the estimated performance of this converter model as a function of power output. Testing of the 3 sq cm converter with an ion bombardment heat source at the General Electric Company's Research Laboratory had just been started as this article was being written. At a 3,600 R cathode temperature a power output of 24 watts, or 8.0 watts per sq cm, was measured. It appeared that the design 10% converter efficiency was achieved.

A goal of this program is to test the thermionic converter model in a simulated space vacuum environment. It is also mandatory that the converter operate in an oxygen-free environment to prevent corrosion, particularly of the encapsulating diaphragm and other high-

Table I. Thermionic Converter Specification

Total weight of converter	0.89 pound
Cathode area	3 sq cm
Anode area	3 sq cm
Effective radiator area*	27.29 sq in
Power output	15 watts
Terminal voltage	1 volt
Cathode temperature	3,600 R
Anode temperature, approximate	1,400 R
Mean radiator temperature, approximate	1,200 R
Converter efficiency	10%
Assumed receiver emissivity	0.90
Focal plane power required	439 watts
Waste heat radiated	135 watts

*The radiator was designed with more area than required because (1) the emissivity of the surface is not precisely known, (2) extra radiator area is needed for exploring power densities greater than 5 watts per sq cm, and (3) effects of varying radiator area will be explored by machining off parts of the radiator.

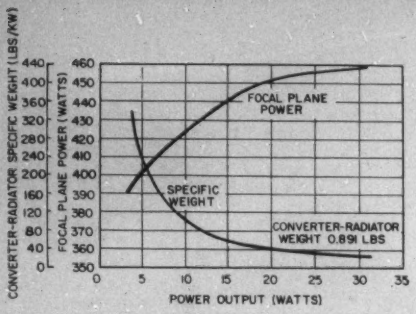


Fig. 5. Estimated performance of thermionic converter model.

temperature components. Therefore, the thermionic converter is placed into a test capsule as shown in Fig. 6, and the capsule is placed in the focal area of the Boeing solar concentrator.

SOLAR HEAT

THE HIGH-PRESSURE cesium-vapor thermionic diode may require 50 to 100 watts of heat per sq cm at 3,600 R. On the other hand, the intensity of solar radiation in space in the vicinity of the earth is only 0.14 ± 0.008 watt per sq cm.[4] Hence, this sunlight must be concentrated to produce the temperatures and heat fluxes required for thermionic converter operation. Even more concentration is required for testing thermionic converters at sea level, where the solar intensity is only about 0.07 watt per sq cm.

Sunlight can be concentrated with either a refractor or a reflector. Refracting concentrators have not been seriously considered for space use because the intense ultraviolet light can deteriorate the lens material if it is a plastic. On the other hand, a first-surface mirror-type concentrator has no light flux going through it, and ultraviolet deterioration is not expected.

A paraboloidal mirror concentrator was selected for this experimental program. The losses in a system employing a paraboloidal mirror are illustrated in Fig. 7 and will be discussed in detail.

Absorber Losses. Radiant solar electromagnetic radiation is converted into sensible heat at the absorber. This heat either enters the thermionic converter where it is partially converted into electric power, or is reradiated away. Heat conducted or radiated from the converter cathode to colder parts of the converter is charged to converter losses.

The heat balance at the absorber is

$$\alpha Q_a = Q_g + Q_r \tag{1}$$

where

α = absorber surface absorptivity (radiation not absorbed is reflected away)
Q_a = radiant energy striking the absorber
Q_g = heat delivered to thermionic generator
Q_r = heat reradiated by absorber = $\sigma A_a \epsilon (T_a^4 - T_0^4)$
A_a = absorber area, sq cm
ϵ = absorber total emissivity at temperature T_a
σ = Stefan-Boltzmann constant = 5.67×10^{-12} watts cm^{-2} deg^{-4}
T_a = absorber temperature in degrees Kelvin
T_0 = temperature of radiation sink, which is negligible in space-use thermionic absorber calculations

From equation 1, the input heat Q_a can be computed if the heat required by the thermionic converter and the emissivity, absorptivity, and temperature of the absorber are known.

A desirable characteristic of the absorber is high absorptivity in the solar spectrum and low emissivity in its own radiation spectrum. Surfaces having these properties are said to be selectively emissive, and such surfaces for lower-temperature absorbers are described in an unpublished paper. As far as we know, no selectively absorptive surfaces suitable for a 3,600 R temperature have been developed. Therefore, the absorber surface will probably be tungsten, tantalum, or some other refractory metal. Heat-balance calculations will show that with tungsten, which has a solar total absorptivity of 0.45 and a 3,600 R emissivity of 0.28, the highest absorption efficiency is obtained by roughening it so that it approaches a black body, which has unity absorptivity and emissivity. For a given net heat absorption, a blackbody absorber requires only 84% of the radiation required by polished tungsten. An emissivity and absorptivity of 0.9 may be attainable with roughened tungsten.

Fig. 6. Test capsule with thermionic converter mounted inside.

Enclosure Loss. Thermionic converters designed for space vehicles must still be tested on the earth, where air is present. To have a realistic test, it is necessary to install the absorber within a vacuum chamber to eliminate convection heat loss. Sunlight in going through the chamber window undergoes a loss in intensity. The enclosure heat balance is

$$Q_a = Q_e t_e \tag{2}$$

where

Q_e = radiant energy striking environmental enclosure
t_e = transmissivity of glass used in enclosure window

Mirror Orientation Loss. As a mirror is misoriented, the focal spot will move with respect to the absorber. If the focal spot is the same size as the absorber, misorien-

tation will cause some of the light to be spilled past the absorber and will result in loss of energy.

One method of analyzing the power lost from misorientation is based on the assumption that the mirror is continually hunting within the orientation error angle. The power loss then can be determined statistically from the amount of time that can be spent at various degrees of misorientation. The results of such an analysis are plotted in Fig. 8. The percentages represent the portion of total reflected energy that is directed on the absorber. By concentration ratio is meant the ratio of the useful area of the concentrator to the area of the absorber.

For low-temperature thermoelectric generators, a 1-degree orientation accuracy will produce reasonable efficiencies. For thermionic converters that require higher temperatures and hence higher concentration ratios, the orientation accuracy needs to be somewhere between 0.1 degree and 0.5 degree.

Loss from Mirror Surface Irregularities. Light striking a gross irregularity on the mirror surface can be reflected in a direction that misses the absorber. For low concentration ratios, large gross irregularities can be tolerated. For example, an umbrella-type mirror which has flat areas between ribs would be satisfactory for a low value of concentration ratio. On the other hand, for the concentration ratios required for high-temperature thermionic converters, no area of the mirror may deviate far from a true paraboloidal surface.

The effect of mirror surface accuracy on efficiency is illustrated in Fig. 9. The term "accuracy efficiency" means the percentage of reflected light that is directed in such a manner that it strikes the absorber. Perfect orientation is assumed. The mirror irregularities are angular deviations from a perfect paraboloidal surface, and the root mean square of these deviations is denoted by the symbol δ. The amount of light flux that misses the absorber as a result of irregularities may be computed for any concentration ratio by an operation involving the integration of the bivariant normal distribution curve of δ.

Mirror accuracy efficiency is plotted as a function of concentration ratio for three values of δ in Fig. 9. The 3.7-degree mirror represents an umbrella-type construction, the 1.0-degree deviation is typical of a crude lightweight mirror, and the 0.308-degree accuracy is attained in heavy searchlight mirrors. It will be noted that at concentration ratios of 1,200 to 2,000, which are required for thermionic generators in space, a 1-degree mirror has such low efficiency that it is not practical. A 0.4-degree accurate lightweight mirror, such as shown in Fig. 10, is required for high-temperature thermionic generators. This mirror weighs 0.4 pound per sq ft (square foot), and mirrors weighing less than 0.25 pound per sq ft have been made since the photograph was taken.

Loss from Mirror Surface Absorptivity. The incoming solar radiation that is not reflected by the concentrating mirror is absorbed and represents a loss.

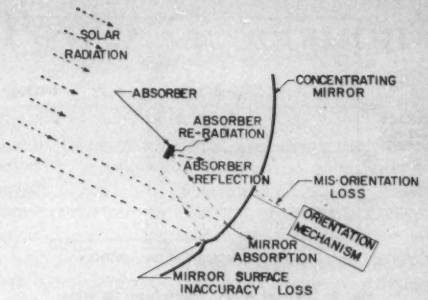


Fig. 7. Solar energy collection losses.

Reflectivities of substantially higher than 90% have been achieved in the laboratory. The effects on reflectivity of the high vacuum in space, Van Allen radiation, and micrometeorite erosion are being evaluated; however, nothing conclusive can be said until an actual mirror surface can be exposed to space conditions and returned for examination.

Recently we coated a lightweight mirror with vacuum-deposited aluminum and silicon monoxide. The measured reflectivity of this surface was:

Wavelength, Angstroms	Reflectivity, per cent
5,500	90.5
5,750	88.0
6,000	91.0

Mirror Distortion. In satellite applications, the effect of mirror front-to-back temperature differences must be considered. The front of the mirror is coated with a high-reflectivity surface which usually is also a poor emitter of heat. The back side of the mirror should be coated with a high-emissivity surface to keep the mirror structure temperature low. This high-emissivity surface at times will look at black space, and at other times will face the earth. As a result, its temperature will change, as will the front-to-back temperature gradient mirror's.

The effect of a front-to-back temperature difference is to cause the mirror structure to bend from differential expansion, resulting in a shift of focus. For example, a 9 F front-to-back temperature difference in a ¼-inch thick mirror would cause a 2.5% change in focal length.

An objective in mirror design is to minimize front-to-

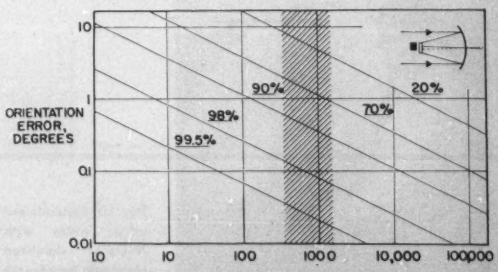


Fig. 8. Effect of orientation error on heat collection.

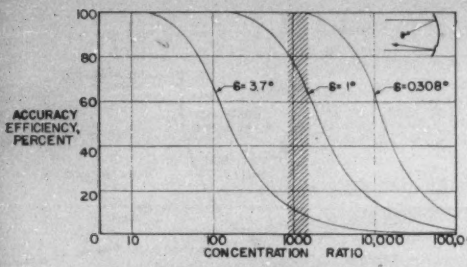


Fig. 9. Effect of gross imperfections in mirror.

back temperature differences by using structural materials with reasonable heat conductivity. One mirror, which is based on Fiberglas-stabilized aluminum honeycomb structure, utilizes bonding resins loaded with silica powder to improve heat conductivity.

It can be shown that with good thermal design the front-to-back temperature difference can be held to within 4 F to limit focal length excursion to ± 0.6%.

Design Considerations. With the aforementioned design criteria, the concentration for a solar-heated thermionic generator can be designed. The mirror must intercept enough sunlight to provide the heat required by the thermionic converter plus the losses resulting from mirror absorption, misorientation, mirror inaccuracies, absorber reflection, and absorber reradiation. Mirror area that is not effective because of radiator shadow must be taken into account. The mirror and the absorber areas establish the concentration ratio. Some design iteration is necessary, because misorientation and mirror inaccuracy losses are a function of concentration ratio.

The following example shows how a mirror design calculation would be made for a space-use 3 sq cm thermionic converter requiring 150 watts of heat and operating at 3,600 R. The absorber is assumed to be tungsten which has been surface treated to give a 0.9 emissivity and 0.9 absorptivity. The numerical values assumed for this calculation have been selected to illustrate the computation, and are not necessarily values that have been experimentally achieved:

Fig. 10. Paraboloidal mirror made with Fiberglas stabilized aluminum honeycomb structure.

Heat delivered to converter	150 watts
Heat reradiated by 3 sq cm	245 watts
Total radiation absorbed	395 watts
Radiation striking absorber when $\alpha = 0.9$	439 watts
Radiation received by mirror, with 0.90 reflectivity $\frac{439}{0.9}$	= 488 watts
Correction for mirror surface inaccuracy (0.4-degree mirror, 1,500 concentration ratio) = 0.96 $\frac{488}{0.96}$	= 508 watts
Correction for power loss from misorientation (0.13-degree accurate orientation, 1,500 concentration) = 0.96 $\frac{508}{0.96}$	= 529 watts
Intercepted area at 130 watts per square foot solar radiation (including 0.1 sq ft converter shadow)	4.17 sq ft
Concentration ratio	1,260
Mirror diameter	2.3 ft

Note: A new computation based on a concentration ratio of 1,260 would not significantly change the results.

A parameter not considered so far is the ratio of mirror diameter to focal length. It has been shown that a ratio of 1.7 gives the highest collection efficiency for parabolic-cylinder mirrors with flat-plate absorbers.[5] Subsequent investigations have established that this is also a good ratio for paraboloidal mirrors with flat-plate absorbers.

The absorber shape is another possible design variable. A cavity-type absorber with a small opening at the mirror focus would reduce reradiation losses, because although the reradiation would occur at an emissivity of 1.0 (black body), the radiating area would be only the area of the small cavity opening. A cavity-type absorber requires a mirror of higher concentration ratio because the mirror must focus on the small cavity opening rather than on a larger flat plate. As a result, mirror structure accuracy and orientation accuracy must be more precise to retain reasonable collection efficiency. Furthermore, front-to-back temperature differences must be very closely controlled to limit focal-point shifts, because the cavity opening must be large enough to admit all incoming light at the greatest excursion of the focal point.

CONCLUSIONS

FROM THE RESEARCH and design work so far completed, the following conclusions can be drawn:

1. A high-pressure cesium-vapor type thermionic converter heated by sunshine concentration by a lightweight mirror appears to be a promising power source for space vehicles.
2. A procedure for designing solar–thermionic space-vehicle power sources has been developed.
3. Tests of a 15-watt solar-heated thermionic converter should establish valid design citeria for these converters.

REFERENCES

1. Theoretical Efficiency of the Thermionic Energy Converter, J. M. Houston. *Journal of Applied Physics*, New York, N. Y., vol. 30, Apr. 1959, pp. 481-87.

2. Calculations of the Performance of a High-Vacuum Thermionic Energy Converter, H. S. Webster. *Ibid.*, pp. 488-92.

3. Conversion of Heat to Electricity by Thermionic Emission, V. C. Wilson. *Ibid.*, pp. 475-81.

4. Solar Constant and Spectral Distribution Factors for Solar Energy Converters Intended for Space Applications, Daniel Friedman. *Memorandum Report no. 1005, U. S. Naval Research Laboratory, Washington*, D. C., Dec. 1959.

5. Optimum Reflector-Absorber Geometry for a Solar Generator, R. W. Stineman. AIEE *Transactions*, pt. II (*Applications and Industry*), vol. 78, Nov. 1959, pp. 332-37.

Magneto-Thermionic Power Generation

A. SCHOCK

A design concept is presented which, under certain conditions, improves the efficiency of thermionic generators. The proposed concept envisages the application of a magnetic field perpendicular to the electrode surface. This applied field counteracts the adverse effect of the self-induced transverse magnetic fields present in large thermionic generators. In addition, the applied magnetic field may be used as a modulating device in order to generate an alternating current.

THE CONCEPT of using thermionic emission for converting heat to electricity without moving parts has been known for many years. Consider a diode comprising a pair of parallel electrodes, separated by a narrow vacuum gap. One electrode, heated to incandescence, emits electrons; the other, which is cooled, acts as a collector. The transmitted electrons are returned to the emitter through an external load, thus converting heat to electrical work. The process may be considered as a heat engine, employing an electron stream as its thermodynamic working fluid. In effect, the electron fluid is evaporated at the hot emitter, and condensed at the collector. [See Fig. 1 (A).]

In the past, the above method was not considered practical, since the electron space charge limited the transmitted current to very low values. Recently, however, interest in thermionic energy conversion has been revived by various suggestions for overcoming this limitation. One suggested method envisages the neutralization of the negative space charge by means of positive cesium ions. In practice, the space between electrodes is filled with low-pressure, low-density cesium vapor. The electron affinity (ionization potential) of a cesium atom is lower than the electron affinity (work function) of the electrode surface (e.g. tungsten). Consequently, a cesium atom impinging on the hot electrode surface gives up one of its electrons, and departs as a positive ion. Since the positive ions tend to neutralize the negative space charge the potential barrier against electron transmission is largely eliminated.

The above system, frequently referred to as a plasma diode, is reported to have achieved efficiencies of 10-15% in small laboratory devices, and offers the theoretical possibility of efficiencies as high as 35%, and power densities of the order of 30 watts per square centimeter of emitter surface. In addition, thermionic energy conversion offers another important advantage. Because of the high heat-source temperature employed (2,000-4,000 F), it is possible to attain good efficiency with a relatively high heat-sink temperature (e.g. 1,000 F). Consequently, it may be possible to utilize the heat rejected by the thermionic unit to generate additional power. This could be done either by employing a more or less conventional steam turbogenerator, or by means of thermoelectric conversion elements. When operating such a combined system, the thermionic unit acts as a high-temperature topping device, and over-all energy conversion efficiencies in excess of 50% may be possible.

In passing, it should be pointed out that the high emitter temperatures required for efficient operation need not present as difficult a problem as may at first appear. Consider, for example, a thermionic generator employing a nuclear heat source. The uranium fuel could be dispersed directly in the emitting electrode. The important point is that the hot electrode is nowhere in contact with the coolant; thus the usual difficulty with corrosive mass transfer is avoided.

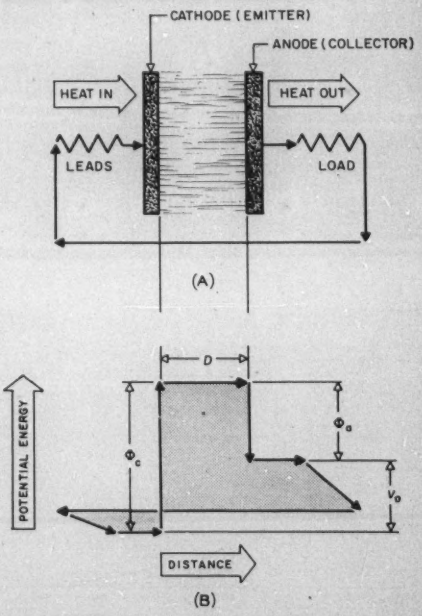


Fig. 1. Thermionic generation: (A) circuit diagram; (B) potential energy diagram.

Revised text of paper CP60-1033 presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the Aero-Space Transportation Committee.

A. Schock is with the Republic Aviation Corporation, Farmingdale, N. Y.

The author is indebted to the many investigators whose studies of thermionic power conversion developed the concepts and understanding which are the foundation of the present analysis. Among his colleagues at Republic Aviation, the writer wishes to thank A. E. Kunen and L. Kraus for their support and encouragement, L. Aronowitz for suggesting the possibility of using a perpendicular magnetic field, and L. Leven, J. Boggi and B. Siegel for programming the numerical computations.

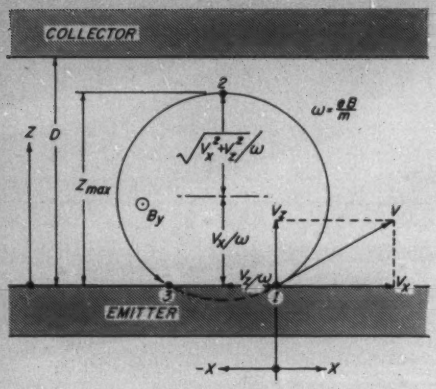


Fig. 2. Projection of helical electron trajectory (magnetic field parallel to emitting plane).

The potential performance of low-pressure cesium plasma diodes in the direct conversion of heat to electricity was analyzed in a number of recent studies.[1-4] Although none of these discuss the effect of magnetic fields on electron transmission, the possible importance of this effect was recognized by several experimentalists,[1,5,6] as evidenced by their careful precautions to eliminate such fields.

While the prevention of magnetic fields is relatively easy in the very small experimental devices tested to date, the problem is far more difficult in the case of a full-scale thermionic generator. Because of its inherently low operating voltage, a high-power generator must of necessity produce a very large current; and this, in turn will induce a sizable magnetic field parallel to the emitting surface. Such a field deflects the electrons, forcing some of them back to the emitter.

TRANSVERSE FIELD EFFECT

THE DETAILED MATHEMATICAL ANALYSIS is presented in a separate report,[7] and will only be summarized here. To simplify the analysis, we assume that the cesium density is everywhere adequate to neutralize the space charge, and that the load impedance is chosen so that the external voltage drop is equal to the difference between the electrode work functions. The latter assumption will, in general, maximize the system's efficiency. As shown by Fig. 1(B), the above assumptions imply a negligible electric field in the electrode gap.

If we restrict our attention to the class of plasma diodes in which the cesium density is low enough so that collisions are negligible, then each electron may be assumed to move under the influence of a pure magnetic field. This field, which is selfinduced by the electron current, is not uniform. However, since the electrode spacing is generally quite close, very few of the electrons travel far from their point of origin. Consequently, each electron throughout its travels sees a transverse magnetic field of essentially constant magnitude and direction.

Under these conditions, each electron follows a helical trajectory about an axis parallel to the transverse magnetic field B_y. The electrons move at an angular speed $\omega = eB/m$ radians per second, where e and m denote the electron's charge and mass. The projection of this helix onto a plane normal to the B_y field is shown by Fig. 2. Clearly, an electron emitted with velocity v at point 1 will return to the emitter at point 3, unless its altitude Z_{max} at point 2 exceeds the electron spacing D. Therefore, to compute the minimum velocity required for reaching the collector, we set $Z_{max} = D$. Electrons which satisfy the resultant equation are those which just graze the collector at the peak of their travel (point 2, Fig. 2). Hence, the equation defines the threshold escape velocity for a given emission direction.

Next, we consider thermionic emission from a hot metal surface. Starting with a Fermi-Dirac energy distribution within the metal, and allowing for the kinetic energy lost in passing through the work function barrier at the metal's surface, we obtain an expression for the velocity spectrum of the emitted electrons.[7,8] Integrating this distribution function over all possible velocities results in the well known Richardson-Dushman equation for the saturated emission current density. If we integrate the same expression, using the previously computed threshold velocity as the lower limit of integration, we obtain an expression for the current density which reaches the collector. Dividing the latter result by the former, we obtain a simple expression for the fraction of the emitted electrons which reaches the collector in spite of the transverse magnetic field:

$$f = \operatorname{erfc} \mathcal{B} = \operatorname{erfc} [eBD\ (8\ mkT)^{-\frac{1}{2}}] \qquad (1)$$

This equation gives the transmission fraction f as a function of the field strength B, electrode spacing D, Boltzmann's constant k, and emitter temperature T. For various values of T, Fig. 3 presents a plot of f vs. the product BD.

As would be expected, increasing the field strength B

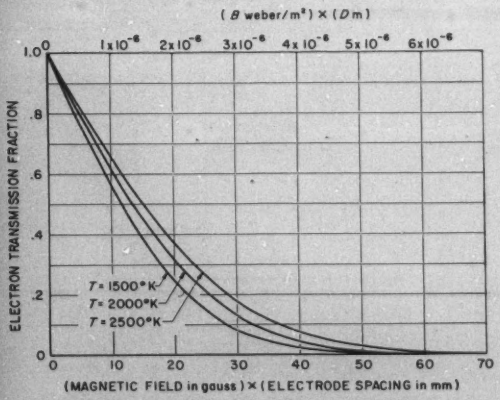


Fig. 3. Electron transmission vs. the product BD.

decreases the transmitted current, since the electron trajectories are bent more sharply. Increasing the electrode spacing D also diminishes the transmitted current, since it makes it more difficult for electrons to reach the collector. Finally, raising the emitter temperature T increases the transmission fraction, by imparting a higher initial velocity to the emitted electrons.

For an emitter temperature of 2,000 K, Fig. 4 illustrates the effect of field strength on transmission fraction for various electrode spacings. Note that even modest field strengths reduce the electron transmission substantially.

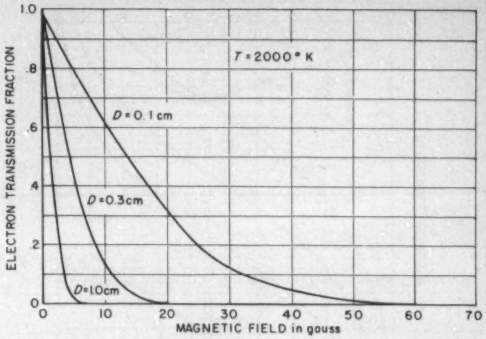


Fig. 4. Effect of transverse field on electron transmission for various electrode spacings.

SELF-INDUCED FIELD EFFECT

THUS FAR, we have examined the effect on electron transmission of a transverse magnetic field having an arbitrary magnitude. Since this field is itself produced by the electron current, a self-consistent coupled solution must exist. For simple axisymmetric configurations, it is easy to express the induced field strength as a function of the transmitted current. For example, for plane parallel disk electrodes, the field strength B at radial position r is given by

$$B = \frac{\mu_o}{2\pi r} \int_o^r J\, 2\pi r'\, dr' = \frac{\mu_o J_o}{r} \int_o^r f r' dr' \qquad (2)$$

where μ_o is the magnetic permeability, and J_o denotes the saturated emission current. Inserting equation 1 for f, and differentiating with respect to r, we obtain the dimensionless differential equation.

$$(d\mathcal{B}/d\mathcal{R}) = \text{erfc}\, \mathcal{B} - (\mathcal{B}/\mathcal{R}) \qquad (3)$$

where

$$\mathcal{B} = [e\ D\ (8\ mkT)^{-\frac{1}{2}}]\ B$$

$$\mathcal{R} = [\mu_o J_o e D (8\ mkT)^{-\frac{1}{2}}]\ r$$

Equation 3 was solved by digital computer, and the solution is presented by Fig. 5. The same figure also shows the radial variation of the transmission fraction $f = \text{erfc}\, \mathcal{B}$, and of f_{avg}, the transmission fraction averaged over the electrode area.

To illustrate the physical significance of the aforementioned results, Fig. 6 depicts the effect of electrode radius R on average current transmission (for typical values of emitter temperature, emission current density, and electrode spacing). Note that even a small electrode ($R = 10$ cm) suffers a sharp drop in current transmission as a result of the self-induced field.

In addition to parallel disk electrodes, the case of coaxial cylindrical electrodes has been analyzed. For this case, the coupled solution is obtained from the equation

$$d\mathcal{B}/dz = \text{erfc}\, \mathcal{B} \qquad (4)$$

where

$$\mathcal{Z} = [\mu_o J_o e D\ (8\ mkT)^{-\frac{1}{2}}]\ z$$

z = the distance from the electrodes' free end

The general solution of equation 4 is presented in Fig. 7, and the effect of electrode length on average current transmission is illustrated by Fig. 8. It is seen that the reduction of electron transmission for this geometry is even more pronounced than in the parallel disk case.

DISCUSSION

IN A THERMIONIC GENERATOR, a major portion of the energy input to the hot electrodes is required to compensate for radiative and conductive heat losses. These heat losses are, of course, independent of magnetic field strength and electron current. Consequently, the field-induced reduction of the transmitted current would bring about a substantial decrease in the generator's power conversion efficiency, as demonstrated by the illustrative example presented later. Under these conditions the attainment of high current density (and efficiency) would only be possible with relatively small electrodes. This severe restriction on allowable electrode size represents a highly undesirable limitation on the freedom of design and would make it quite difficult to build an efficient high-power generator.

To avert this difficulty requires one of two things; either some electrode configuration which produces large currents without inducing strong magnetic fields; or a system permitting high current transmission in spite

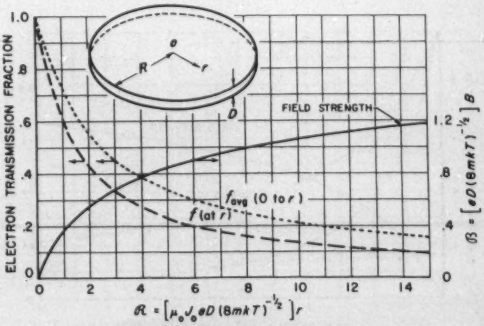


Fig. 5. Interaction of electron current and selfinduced magnetic field. General solution for parallel disk electrodes.

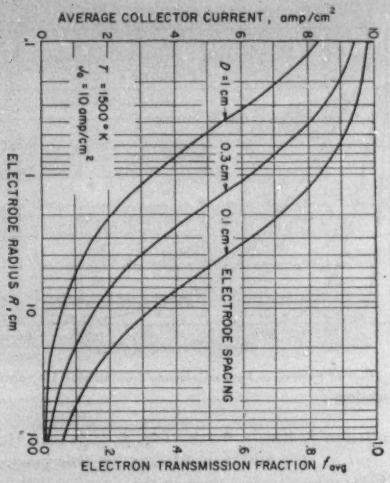


Fig. 6. Effect of disk electrode size on current transmission.

of the large self-induced field. To attain the latter objective, we propose the concept of the "Magneto-Thermionic Generator," in which a longitudinal magnetic field B_z (parallel to the direction of current flow) is superimposed on the self-induced transverse field B_y.

LONGITUDINAL FIELD EFFECT

As shown by Fig. 9, the combined magnetic field intersects the emitting plane at an angle α, whose value depends on the relative magnitudes of the longitudinal and transverse field components. Solving the equations of electron motion, we again find that the electrons follow a helical trajectory about an axis parallel to the field lines. This time, however, not every trajectory returns to the emitting plane. The electron motion may be compared to a man climbing a circular staircase in an inclined tower.

The variation of altitude Z vs. time; i.e., the electron motion perpendicular to the emitter, is a sinusoidal function superimposed on a constantly ascending base line. The emitted electrons may be divided into three groups, as illustrated by Fig. 10. Group I electrons ascend monotonically, while Group II and III pass through successive maxima and minima. Group II consists of those electrons whose first minimum value of Z is positive, while the electrons with negative Z_{min} belong to Group III.

Clearly, Groups I and II escape the emitting electrode. As for Group III, those electrons whose value of Z_{max} exceeds the electrode spacing D will also reach the collector. However, we are primarily interested in reasonably large electrode spacings, and in strong magnetic fields (i.e., small helical diameters). Under these conditions, the number of electrons whose $Z_{max} > D$ is very small; hence it was assumed that *all* Group III electrons return to the emitter. Since this approximation underestimates the fraction of electrons transmitted, the results obtained are conservative. The above assumption not only simplifies the analysis but also improves its generality, since the fractions of electrons in Groups I and II depend only on the field direction α and are independent of the field strength B and electrode spacing D.

Solving the equations of electron motion for Z_{min}, and setting the result equal to zero, we again obtain a threshold equation for electron escape. All electrons which satisfy this equation just graze the emitter surface at the end of their first return loop. The equation, therefore, defines the critical relationship between the initial velocity components, and separates the electrons reaching the collector from those which fall back to the emitter. It was found that a given electron's fate depends only on its initial direction, but is independent of its speed. We therefore transform the emission velocity distribution from Cartesian to polar co-ordinates, and use the threshold velocity relation as the lower integration limit. After much computation, we obtain a very simple expression for the transmission fraction f; i.e., the fraction of electrons in Groups I and II:

$$f = \sin\alpha = B_z/(B_y^2 + B_z^2)^{\frac{1}{2}}$$

Fig. 11 shows that with matched fields ($B_z = B_y$) over 70% of the emitted electrons reach the collector, and that a longitudinal field of twice that magnitude

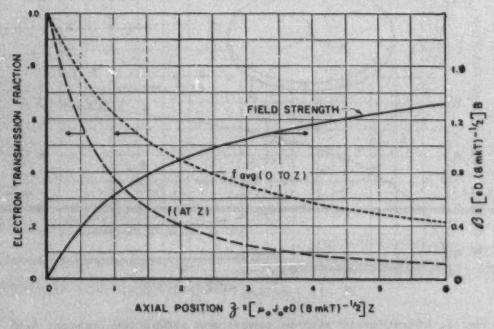


Fig. 7. General solution for coaxial cylindrical electrodes.

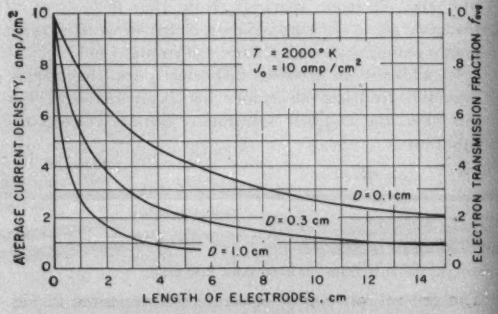

AVERAGE CURRENT DENSITY, amp/cm²
ELECTRON TRANSMISSION FRACTION f_avg
LENGTH OF ELECTRODES, cm
T = 2000° K
J₀ = 10 amp/cm²
D = 0.1 cm
D = 0.3 cm
D = 1.0 cm

Fig. 8. Effect of cylindrical electrode length on current transmission.

($B_z = 2B_y$) permits 90% electron transmission. In other words, an applied field of reasonable magnitude permits efficient operation in spite of the self-induced deflecting field.

ILLUSTRATIVE EXAMPLE

THE FOLLOWING EXAMPLE is designed to illustrate a typical magneto-thermionic generator. Its purpose is to examine the effect of magnetic fields on power density and efficiency, and to ascertain what fraction of the generated power is required to produce the longitudinal field. Since our main interest is in relative rather than absolute performance, any reasonable assumptions may be employed.

Consider a generator consisting of a 4-foot-high stack of plane disk electrodes, 3 feet in diameter. Altogether, there are 50 unit cells connected in series, each cell consisting of one hot and two cold electrode disks (so that both sides of the emitters are utilized). The cathodes contain enough fissionable fuel to make the entire assembly a critical reactor. Thus, the heat is generated within each emitting disk. Assuming a cathode work function of 2.2 volts and a temperature of 2,225 F, the Richardson-Dushman equation gives a saturation current density $J_0 = 10$ amperes per square centimeter. If none of the emitted electrons were turned back by the self-induced magnetic field, such a generator would produce a current of 131 (ka) kiloamperes.

However, it is easily shown from equation 2 that a 3-foot electrode, operating at the current density J_o, would generate a B_Θ field of 572 gauss at the disk's periphery. As shown in Fig. 4, a parallel magnetic field having even a small fraction of this strength would force practically all of the electrons back to the emitter. Actually, for a 0.3-cm spacing between 3-foot electrode disks ($R = 45.7$ cm), Fig. 6 shows that only 4.5% of the emitted current (i.e., 5.9 ka) reaches the collector.

To avoid this difficulty, we wish to impose a magnetic field B_z perpendicular to the electrode disks. Assume that the cylindrical generator is surrounded by three closely wound coils of ½-inch aluminum tubing, connected in parallel with the electrical load. Such a coil, using less than 1% of the power generated, would produce a B_z field of 1,130 gauss, which is twice the magnitude of the *maximum* B_Θ field. For this field ratio, Fig. 11 shows that 90% of the emitted electrons reach the collector. Thus, the *average* current transmission of the proposed design is between 90% and 100%, compared to the 4.5% transmission attainable without the B_Θ field.

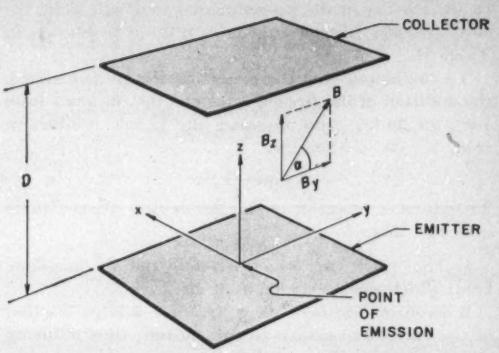


Fig. 9. Combined transverse field (B_y) and longitudinal field (B_z); tan $\alpha = (B_z/B_y)$.

To assess the effect on conversion efficiency, we assumed an anode work function of 1.08 volt, a temperature of 440 F, and electrode emissivities of 0.3. For this design, calculations show an optimum lead resistance of 0.12 volt per cell. This leaves an external voltage drop of 2.2 — 0.12 — 1.08 = 1.0 volt per cell, or a total load voltage of 50 volts. The postulated design is summarized by Fig. 12 and the results of its analysis are shown in Table I.

Table I. Energy Balance (With B_z Field)

Heat Input:	(kw)	*Electric Output:*	(kw)
Electron Cooling	16,100	Gross Power Produced	6,850
Lead Conduction	1,800	Loss in Leads	810
Thermal Radiation	3,200	Field Coil Power	57
TOTAL	21,100	NET	5,983

Over-all Efficiency = 5,983/21,100 = 28.4%

Table II. Energy Balance (Without B_z Field)

Heat Input:	(kw)	*Electric Output:*	(kw)
Electron Cooling	725	Gross Power Produced	330
Lead Conduction	205	Loss in Leads	17
Thermal Radiation	3,200		
TOTAL	4,100	NET	313

Over-all Efficiency = 313/4130 = 7.6%

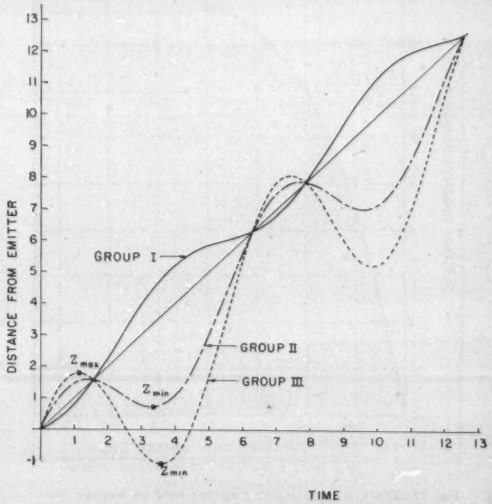


Fig. 10. Electron motion typical of Groups I, II, III.

In the absence of the perpendicular magnetic field, the corresponding energy balance would be as shown in Table II.

To summarize—for the generator design postulated, the addition of the B_z field improves the efficiency from 7.6% to 28.4%, and increases the power production from 313 kw to 5,983 kw.

CONCLUSIONS

THEORETICAL ANALYSIS of the *low-density* plasma diode indicates that:

1. The high currents generated induce magnetic fields which deflect the emitted electrons.
2. Even modest field strengths force a large fraction of the current to return to the emitter, thus reducing the energy conversion efficiency.
3. As a result, cylindrical or plane electrodes, unless kept to a relatively small size, should prove quite inefficient.
4. This undesirable design limitation on electrode size is eliminated in the magneto-thermionic generator. This concept employs external field coils to produce a magnetic field perpendicular to the electrode surface.
5. With an applied field of suitable magnitude, almost complete electron transmission can be achieved.

If experiments confirm the predicted effect of the perpendicular field, the magneto-thermionic generator could produce a fluctuating d-c output by means of a modulated field-coil current. If this output current is then passed through a transformer, its a-c component can be extracted and stepped up in voltage to match the load requirements.

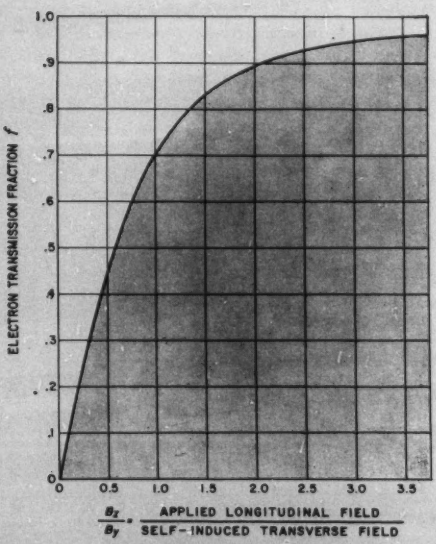


Fig. 11. Effect of longitudinal magnetic field on electron transmission.

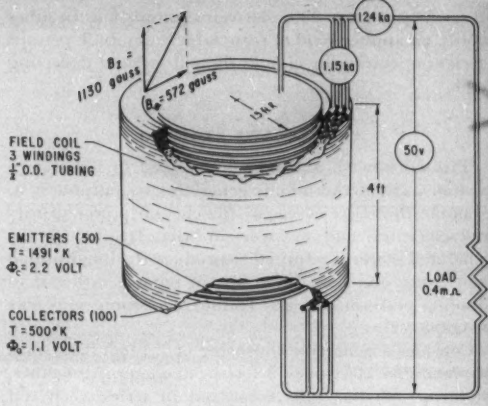


Fig. 12. Illustrative example.

REFERENCES

1. Thermionic Energy Converter, K. G. Hernquist, M. Kanefsky, F. M. Norman, *RCA Review*, Princeton, N. J., vol. 19, p. 244, 1958.
2. "Space Charge Neutralization by Positive Ions in Diodes" P. L. Auer, H. Hurwitz, *Journal of Applied Physics*, New York N. Y., vol. 30, p. 161, 1959.
3. Theoretical Efficiency of the Thermionic Energy Converter, J. M. Houston. *Ibid.*, 1959, p. 481.
4. Figure of Merit for Thermionic Energy Conversion, N. S. Rasor, *Ibid.*, vol. 31, 1960, p. 163.
5. Conversion of Heat to Electricity by Thermionic Emission, V. C. Wilson. *Ibid.*, vol. 30, 1959, p. 475.
6. Characteristics of a Plasma Thermocouple, R. W. Pidd et al., *Ibid.*, 1959, p. 1861.
7. Effect of Magnetic Fields on Thermionic Power Generation, A. Schock. Report No. PPL-TR-60-1, Republic Aviation Corp., Farmingdale, N. Y., Jan. 1960.
8. Electronics (book), J. Millman, S. Seely. McGraw Hill Publishing Company, New York, N. Y., 1941, Chap. IV, V.

Ionization Transducer

The Decker Corporation, Bala Cynwyd, Pa., an independent research and development facility, has developed an analog capacitance-to-voltage transducer that makes capacitive gauging practical and simple. Called the Decker *T-42* Ionization Transducer, it has an optimum operating range of 1 to 20 μμf and simplifies the analog conversion to electric signal for a variety of physical quantities. A complete gauging system with full stability and sensitivity is possible with the T-42 and only three vacuum tubes. This transducer has achieved unique success in differential and absolute pressure measurement, as a microinch micrometer, a gyroscopic angular pickoff, and in the measurement of properties related to high-speed rotating devices (e.g., run-out, gas bearing clearances, and dynamic unbalance).

The Decker Corporation has also developed a gyroscopic true mass flowmeter, the Decker Gyroflo, which will measure flow in either direction to accuracies of 0.5% or better in most applications.

Design of a Solar-Powered Thermionic Diode

W. J. LEOVIC
MEMBER AIEE

M. W. MUELLER

Intense interest in thermionic conversion in the field of space power supplies rests on two inherent properties of this type of conversion process: (1) solar energy can be converted to electric energy without use of moving parts of any kind; and (2) diode anode can operate at temperatures between 600 and 1,500 K permitting efficient rejection of heat by radiation only. Diode has additional advantages of instant and repeatable start–stop capabilities.

BEFORE examining the potential characteristics of the thermionic converter, a quick review of its basic design and a description of "how it works" are perhaps in order. The thermionic diode

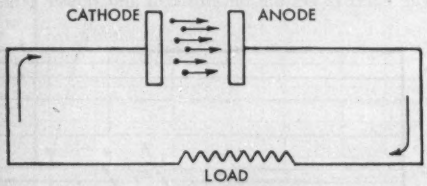


Fig. 1. Thermionic converter.

basic design is quite simple in concept. It is composed of a cathode (emitter) and an anode (collector). The cathode has a high work function relative to the anode. It is heated to a temperature at which electrons are emitted according to the thermal excitation level. The cathode and anode are separated by a distance of about 1 mm (0.039 inch) and cesium vapor is injected between the two surfaces. Thermal ionization of the cesium occurs by virtue of the vapor coming into contact with the hot cathode. The positive ions produced neutralize the electron space charge surrounding the cathode, thus permitting electron current to flow to the anode without space charge limitation. The electric circuit is completed through an external load. The thermionic converter is shown schematically in Fig. 1. The potential energy diagram is shown in Fig. 2. W_C is the work function of the cathode, W_A is the work function of the anode, and $V_L = IR$ is the voltage across the load in the external circuit.

A number of theoretical analyses have been performed in an attempt to describe the performance characteristics of the thermionic diode accurately. Table

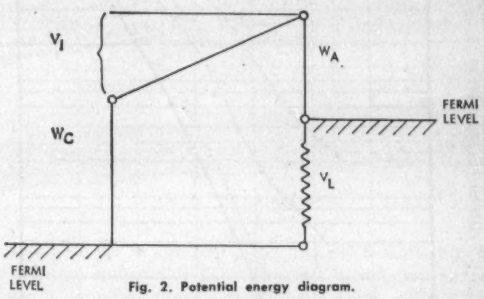


Fig. 2. Potential energy diagram.

I was prepared by Dr. J. R. Reitz. It illustrates the potential performance characteristics for the thermionic converter operating under a variety of conditions.

STATE OF THE ART–THERMIONICS

IN RECENT YEARS considerable effort has been expended in trying to prove the validity of the theories governing thermionic power generation. More recently the plasma diode has been the subject of several ex-

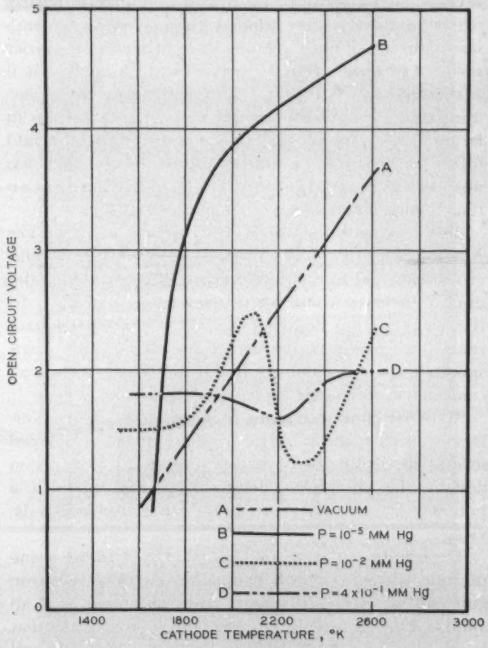


Fig. 3. Open-circuit voltage vs. cathode temperature tantalum emitter.

Essentially full text of conference paper 60-1042 presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the Aero-Space Transportation Committee.

W. J. Leovic and M. W. Mueller are with the Thompson Ramo Wooldridge, Inc., Cleveland, Ohio.

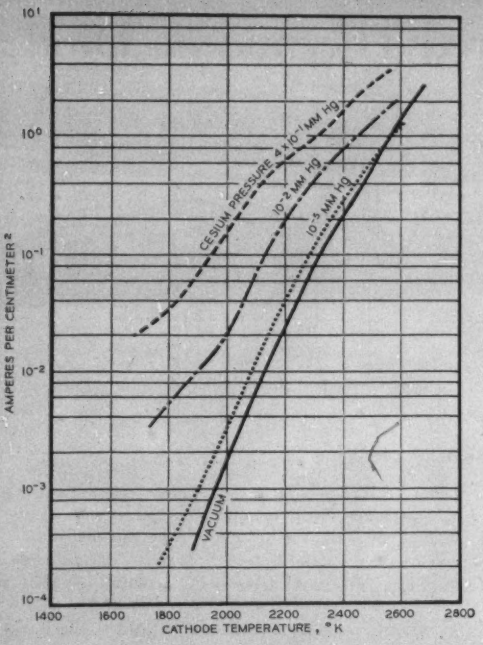


Fig. 4. Short-circuit current vs. cathode temperature. Tantalum emitter.

tensive development and test programs. The literature reveals test data covering vacuum and plasma devices which produce power outputs ranging from a few milliwatts to a few watts per square centimeter of emitter surface. In most instances it has been assumed that if a thermionic effect could be demonstrated in a vacuum tube device with low efficiency, the transition to larger, higher powered, more efficient devices would follow as a matter of course. Unfortunately, such has not been the case and only a few efforts have shown that higher power outputs are realizable.

The first and most succesful effort was made by Los Alamos Scientific Laboratory. The activities of this group have led to the development of electron-gun and nuclear-powered converter configurations that have delivered current at densities over 60 amperes per square centimeter for several square centimeters. This corresponds to a power density of over 30 watts per square centimeter of emitter surface.

A second effort is now in progress at the TRW New Devices Laboratories where a program has developed several successful solar-powered thermionic conversion devices. To date these devices have demonstrated a potential at least as great as the nuclear-powered devices.

The configuration of the Los Alamos diode is a simple one—an emitter disk that is heated by an electron gun and an oil-cooled copper tube which serves as an anode. The emitter is mounted in a large plate that is clamped on a knife edge to provide a hermetic seal to retain cesium vapor in the region between the emitter disk and the copper anode.

Several emitter materials (principally tantalum, zirconium carbide, uranium carbide and zirconium carbide-uranium carbide) were evaluated using this configuration. Each of these materials was studied and the effects of cesium pressure and temperature were observed. Typical sets of performance curves have been published and are reproduced here for purposes of comparison and illustration. The effect of cesium in modifying open-circuit voltage is very well illustrated in Fig. 3. It is rather difficult to state the reason for the indicated voltage variation. Most of the deviation from the vacuum voltage curve may be attributed to the modification in work function of the cathode and anode surfaces. The variation with temperature also would depend on the extent of surface area modified by cesium. For example, as the cathode temperature is raised, less and less cesium will remain on the surface and the work function of the cathode will rise as the ratio of patched to clean surfaces is reduced. It may be assumed that some variation in anode work function will also occur with changes in temperature.

The effect of cesium on emission and power genera-

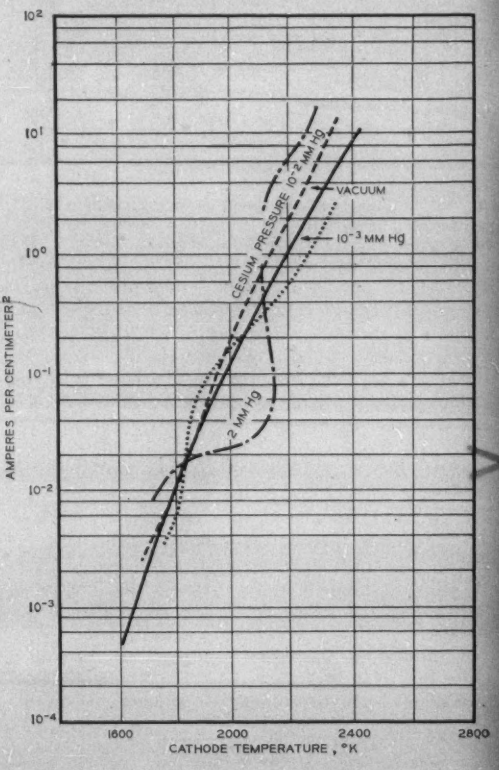


Fig. 5. Short-circuit current vs. cathode temperature. Zirconium carbide emitter.

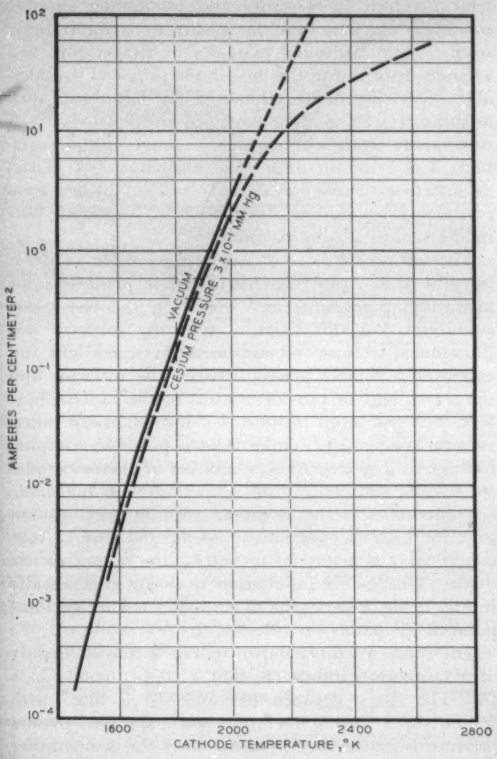


Fig. 6. Short-circuit current vs. cathode temperature. Uranium-zirconium carbide emitter.

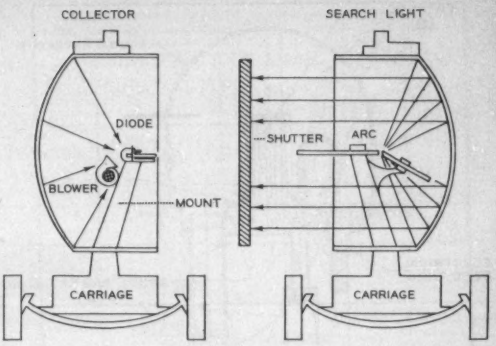


Fig. 7. Test rig schematic.

tion capabilities is very marked, as can be seen in Fig. 4. The modification of the emitter work function immediately gives rise to emission rates in excess of saturation emission characteristics obtained in vacuum. Again as the temperature is raised, the proportion of modified surface is reduced and the apparent work function approaches that of the clean emitter material, thus reducing the emission rate to the normal saturation level or below. The indication is that for metals with high work functions, such as tantalum or tungsten, the emission characteristics may be increased considerably beyond the extent shown in these curves simply by increasing the cesium pressure.

For the materials with naturally low work functions, such as the zirconium carbide shown in Fig. 5, there is much less effect due to surface modification. Zirconium carbide normally exhibits a work function of 3.5 volts which makes it less sensitive to the deposition of the 1.81-volt cesium. It is still apparent, however, that the cesium vapor neutralizes the electron space charge, permitting near saturated emission at all times.

Fig. 6 illustrates the favorable results which may be obtained with more ideal emitter materials. It has been shown that tantalum will emit approximately 1 ampere per square centimeter at 2,400 K while Fig. 6 shows an emission of 30 amperes per square centimeter for a uranium carbide-zirconium carbide emitter at the same cathode temperature. This gain in performance coincides wih a rise in cell efficiency from 5% with tantalum to 15% with the carbides.

DIODE DEVELOPMENT IS INTENSIFIED

THE RESULTS OBTAINED from Los Alamos indicated that the field of thermionics was one which held much promise and therefore warranted a more extensive de-

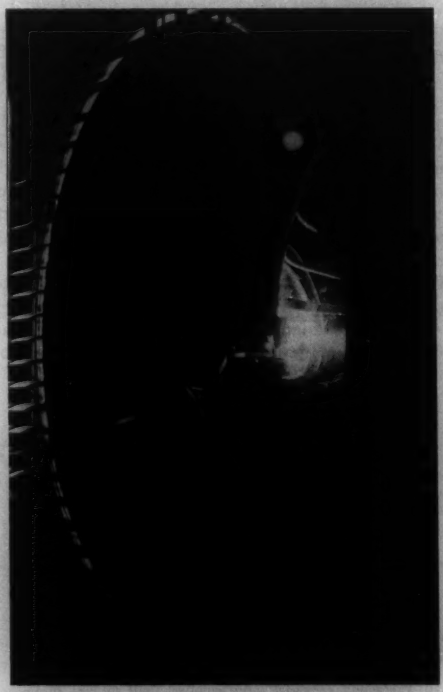


Fig. 8. Thermionic diode converter under simulated solar testing.

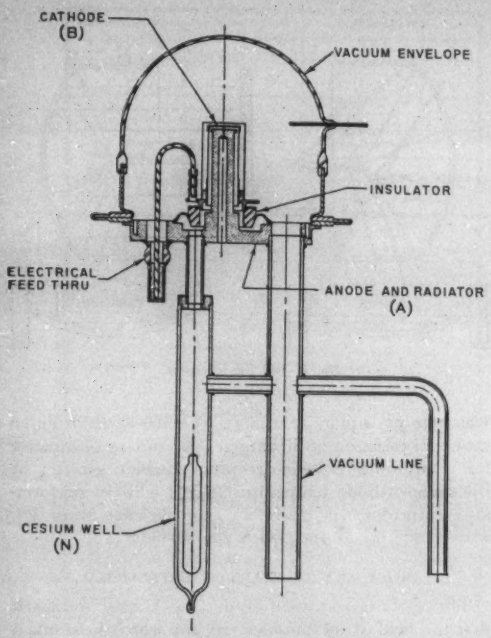


Fig. 9. Thermionic converter assembly.

velopment effort. A brief evaluation of thermionic converter properties and consideration of the possible application of such a device led to the creation of a project to develop a solar-powered diode for use in space or at remote ground stations.

After a period of study, a design configuration was conceived and built. This first feasibility test model incorporated a large number of special materials, processes, and design considerations consistent with the complex problems associated with plasma diode devices.

The general shape of the test unit was governed largely by the requirements for a vacuum environment for the diode elements, the necessity of having a suitable package for mounting in a test rig, and the problems involved in selecting and assembling suitable materials which possess the ability to transmit light, insulate, and withstand extremes in temperature and vacuum. Fabricating this first diode provided considerable experience in special fabricating techniques such as spinning and welding tantalum and brazing metals to ceramics and materials such as tungsten and tantalum. The selection of metals, insulators and glasses to match expansion coefficients and to insure compatibility with cesium also played an important part in the success of this assembly.

The test rig consisted of a 60-inch parabolic collector (surplus U.S. Army searchlight) with provisions for mounting, positioning and observing the test diode assemblies. For this series of tests the collector was illuminated by a second surplus Army searchlight and employed a shutter placed between the collector and the searchlight to provide control of the radiant heat flux. The test setup included a 2-inch diffusion pump vacuum system, a hydraulic 7½-ton portable crimping tool for sealing feed lines, a number of thermocouples for sensing and controlling temperatures in the diode test assemblies, a thermocouple vacuum gage, an ion gage for high-vacuum measurement, and several voltmeters and ammeters for measuring the output of test diodes. The test rig installation is shown schematically in Fig. 7. Fig. 8 shows the diode under test in the focal point of the parabolic collector.

The diode assembly shown in Fig. 9 consists mainly of a tantalum cathode (B) and a copper anode base (A). The space between (A) and (B) is filled with cesium vapor during operation and a specified plasma pressure is maintained by controlling the temperature of the cesium well (N) with an auxiliary heater and Simplytrol controller.

The glass envelope, tubes, insulator rings, etc., are merely accessories required to provide a suitable working environment for the diode elements and to conduct the electric currents generated by the thermionic converter.

The cathode and anode structure with the alumina insulator and associated mounting rings necessary to fabricate the various materials into a single unit are shown in Fig. 10. Fig. 11 shows the prototype thermionic converter. One of the primary reasons for the suc-

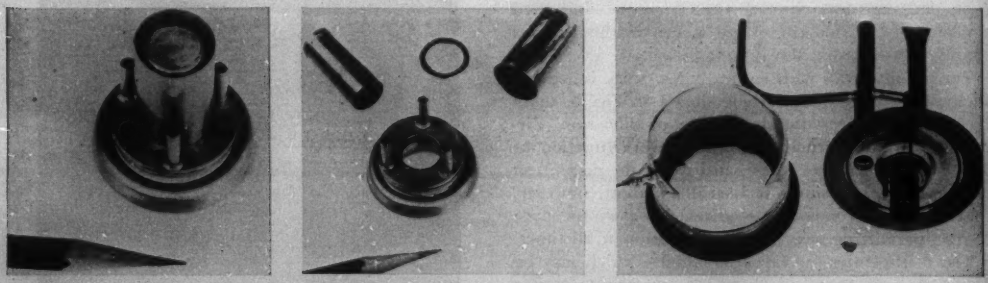


Fig. 10. Thermionic converter subassemblies: (*left*) cathode assembly; (*center*) cathode, radiation shield, insulator subassembly; (*right*) completed assembly prior to bell jar seal.

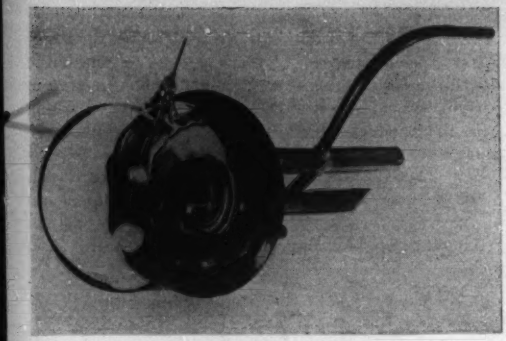


Fig. 11. Prototype thermionic converter.

cess of this test assembly is that extreme care had been taken to assure the cleanliness of all component parts. During the third and fourth test runs some contamination and discoloration of the bell jar was noted and is attributed to a minute cesium leak through a porous braze in one of the Kovar alumina joints. Prior to this, only a very slight trace of discoloration could be detected as a result of outgassing under elevated temperatures.

In the third test a period of only 10 to 15 minutes at elevated temperature was required to produce a large gain in current output from the diode. This contrasted with a reported 8 to 10 hours "age in" time required by Los Alamos in their experiments.

In evaluating the output of the assembly on a unit area basis, the projected area of the anode was 0.713 sq cm with a gap of 0.039 inch or 1 mm between cathode and anode.

A considerable amount of data was taken during the test program. Some of this data will be presented here to permit a comparison with the Los Alamos data and to offer further insight as to the mode of operation of the plasma diode and its potential capabilities.

Fig. 12 shows the relation between vacuum emission voltage and voltage with plasma modification of the diode elements. It should be noted that these curves are plotted against anode temperature because accurate pyrometric measurements could not be made of the cathode. Later calculations indicated that a temperature of 2,200 K was the maximum cathode temperature attained. The same marked increase in open-circuit voltage was noted with this unit at low cesium pressures (or temperatures) as was indicated by the Los Alamos data. Here again the lowering of the anode work function due to the deposition of the 1.81-volt work-function cesium on 4.75-volt work-function copper combined with a slightly modified cathode at higher temperatures gives rise to much larger terminal potentials than are experienced under vacuum conditions.

The load voltage and current characteristics vs. power input roughly indicated by anode temperature which is proportional to the heat rejected are shown by Fig.

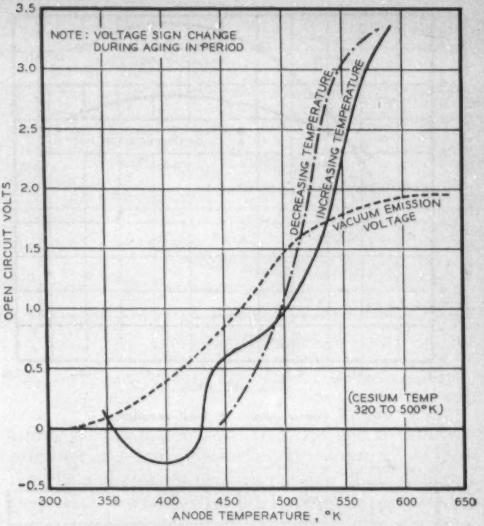


Fig. 12. Open-circuit voltage vs. anode temperature.

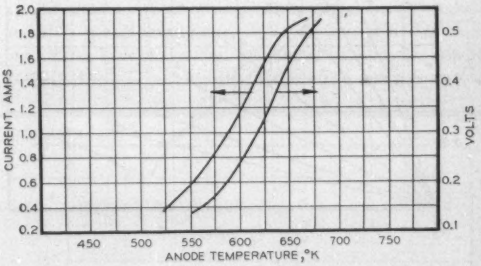


Fig. 13. Load current and voltage vs. anode temperature.

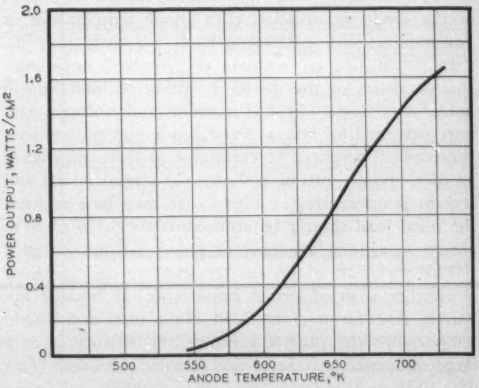


Fig. 14. Power output vs. anode temperature.

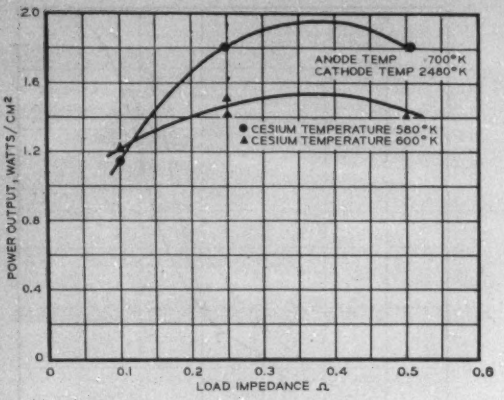


Fig. 15. Power output vs. load impedance.

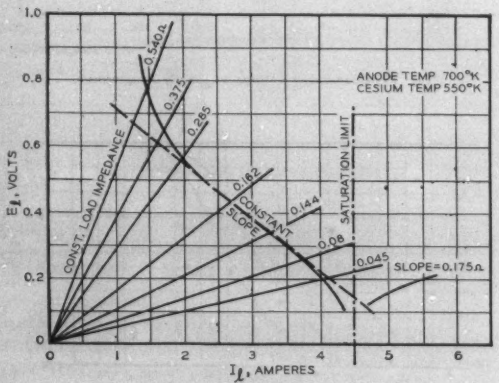


Fig. 16. Voltage vs. current.

13 for a 0.25-ohm load. Fig. 14 shows the power output of the diode again relative to anode temperature or power input with a 0.25-ohm load.

In attempting to evaluate the internal impedance characteristics of the diode, a variety of load impedances were used. Typical current and voltage data were obtained for several fixed anode and cesium temperatures. The effect or variations in load impedance on diode power output is shown for several anode and cesium temperatures in Fig. 15. It may be seen that the ideal load should be approximately 0.375 ohm to obtain maximum efficiency or power output.

The variation of cesium temperature and pressure is another item of prime importance. It became apparent that for a given load impedance and anode temperature the plasma pressure and density have a large influence on the diode current densities. Test data indicate that for a given set of cathode and anode materials there will be an optimum plasma pressure at which the greatest power output and efficiency may be realized. It will be necessary to test each of the likely material combinations very extensively to determine this optimum combination. To determine maximum current densities, cesium pressure was varied along with the anode and cathode temperatures. The maximum total current for this diode with the cathode at nearly 2,200 K was approximately 4.2 amperes with a 700 K anode temperature and a cesium temperature of 525 K.

The internal impedance of the cell is shown char-

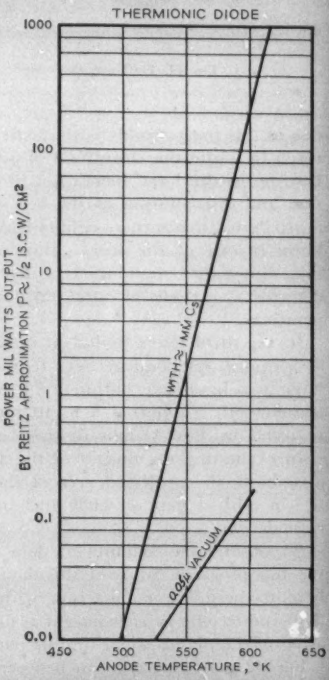


Fig. 17. Power output vs. anode temperature.

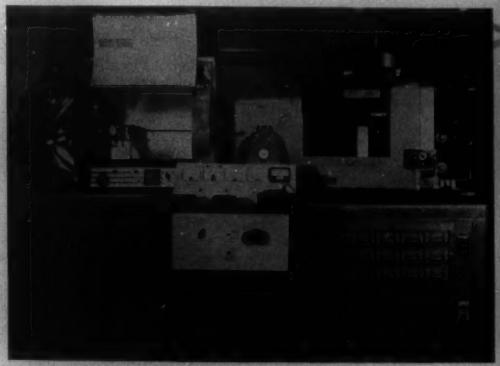


Fig. 18. A.D.L.—Strong arc-imaging furnace.

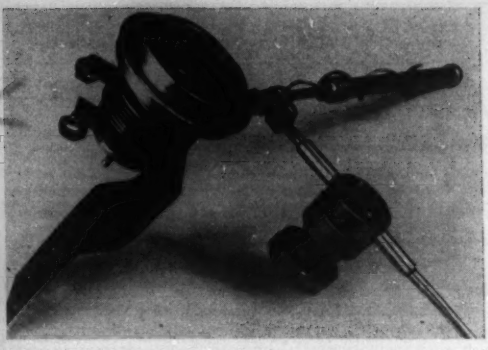


Fig. 19. Design diode in furnace-mounting bracket.

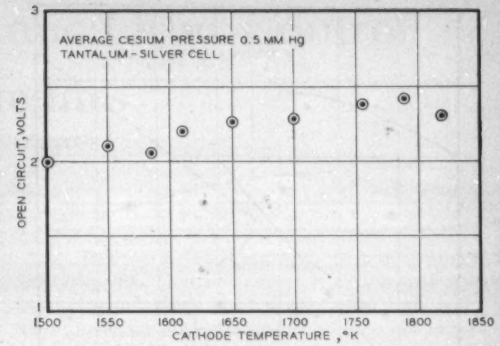


Fig. 21. Open-circuit voltage with cesium vs. cathode temperature.

acteristically in the voltage vs. current curve of Fig. 16. Also noted is the apparent internal impedance value of 0.175 ohm for the emission region between 2 and 4 amperes. Maximum power output occurs at the higher load impedances, approximately 0.375 ohm, where the characteristic curve breaks away from the line of constant slope. This region (between 2 and 4 amperes) is plasma limited and results in a continuous increase in voltage drop until complete saturation is reached by the emitter material.

The most encouraging picture is presented in Fig. 17 where a comparison is made between emission power output with and without the presence of cesium vapor. Ultimately, gains in current density and power output on the order of 10^4 have been recorded and there is every indication that this is not the limit in improvement which may be expected in diode performance.

Following this first successful test effort a revised design was conceived to improve the attainable power densities and efficiency of the diode. Also, many improvements were made in the test facilities. The Solar Simulator Searchlights were replaced by an A.D.L.–Strong arc-imaging furnace (Fig. 18) and a variety of precision test instrumentation was acquired to facilitate the gathering of data on the new diode configuration. Five assemblies of this type were prepared to permit the complete study of diode properties, emitter materials, anode materials, cathode configurations and insulator materials. This series of tests is not yet complete and only a small amount of data is available at the time of this writing. This diode design, designated Type B configuration, is shown in its furnace mounting bracket in Fig. 19. Fig. 20 shows the diode mounted in the focal point of the arc-imaging furnace.

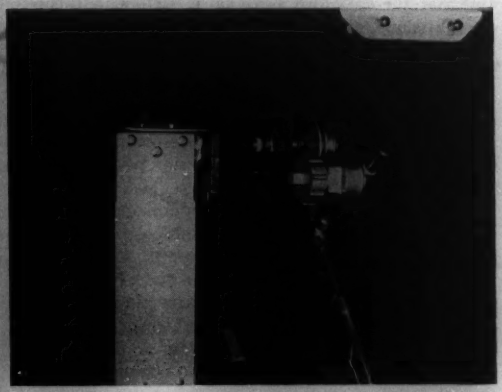


Fig. 20. Design diode mounted in focal point of arc-imaging furnace.

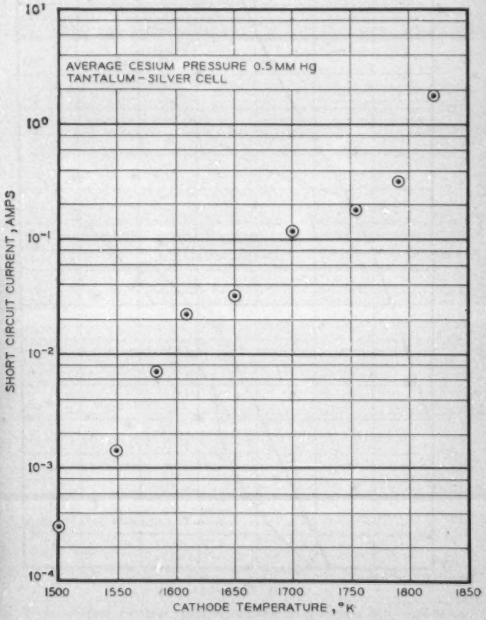


Fig. 22. Short-circuit current with cesium vs. cathode temperature.

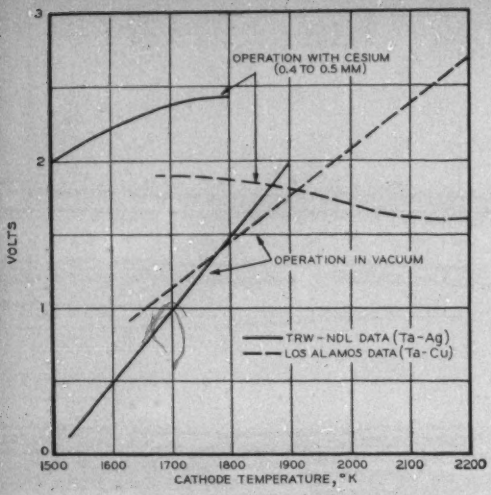


Fig. 23. Open-circuit voltage vs. cathode temperature.

Figs. 21 and 22 show the large open-circuit voltage obtained with the plasma diode and a rapidly ascending current output level. It seems certain that with the materials used here a few hundred degrees increase in temperature will result in an increased power output. Assuming a load voltage of approximately 1.1 volts (one-half open-circuit voltage), an extrapolation of current density to a cathode temperature of 2,050 K would result in a power output of 65 watts or 32½ watts per square centimeter of cathode. Attaining a power density of this order at such a moderate cathode temperature would represent a major achievement in creating high efficiency in a device of this type.

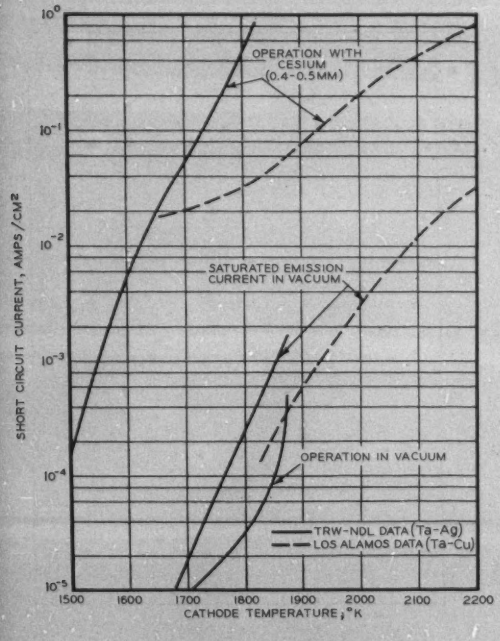


Fig. 24. Cell current vs. cathode temperature.

Table I. Output Voltage and Efficiency of a Plasma Thermocouple Under Various Operating Conditions*

J (amps/cm²)	V_c (volts)	η_i	η	η'
Case 1:				
5	2.28	0.504	0.065	0.268
10	2.14	0.488	0.103	0.309
25	1.91	0.448	0.168	0.321
50	1.64	0.386	0.193	0.287
75	1.24	0.289	0.160	0.213
Case 2:				
10	1.94	0.461	0.099	0.286
25	1.64	0.399	0.145	0.280
50	1.41	0.342	0.168	0.250
75	0.95	0.226	0.121	0.159
Case 3:				
2.5	2.22	0.502	0.054	0.243
5.0	1.81	0.415	0.078	0.248
7.5	1.45	0.339	0.083	0.215

* Case 1: $T_c = 2900$ K, $J_s = 100$ amps/cm², 1-mm plate spacing.
Case 2: $T_c = 2900$ K, $J_s = 100$ amps/cm², 2-mm plate spacing.
Case 3: $T_c = 2550$ K, $J_s = 10$ amps/cm², 1-mm plate spacing.
The efficiencies η and η' refer to the complete thermionic converter circuit. η' in the last column has been calculated with the radiation term Pr reduced by a factor of ten.

The results of this second test series are incomplete because of certain limitations in the arc-furnace setup. Presently, the arc-imaging furnace is undergoing a modification which will allow the higher cathode temperatures, which are desirable for high-power density and efficiency, to be obtained. The data obtained for the lower cathode temperature regions however were most satisfactory.

There are several comparisons made between these data and the results given by Los Alamos in Fig. 23. It may be seen that there is reasonable agreement between the vacuum characteristics of the two test cells and that the data also agree fairly well with theoretical emission calculations. With the introduction of cesium the TRW diode is seen to excell in both voltage and current output. It would appear that the selection of silver for the anode material, the use of very high purity tantalum for the cathode, and possibly an assist due to photoionization of the cesium vapor all contribute as expected to the superior performance of the TRW diode design.

The results to date are most promising. It is particularly interesting to note the high current level attained with a cathode temperature of only 1,860 K. This ability of a plasma diode to yield high current densities at relatively low temperatures will result in higher over-all efficiency at these temperatures and will simplify the mechanical design of the diode as well as reduce the concentration ratio requirements of the solar collection system.

Magnetohydrodynamic Orbit Control for Satellites

S. T. DEMETRIADES

Successful orbit control requires electric propulsion systems capable either of frequent refueling and/or of very high specific impulse. The theory of the magnetogasdynamic (MGD) ramjet and the MGD rocket is developed and the power requirements as well as some of the design considerations are given. Practical problem areas are outlined and some of the present equipment is described.

ECONOMICAL conquest of space will follow the conquest of the upper atmosphere by powered and controlled vehicles of long endurance.

Since the aerodynamic lift provided by a lifting surface at orbital speeds even at the low altitude of 50 miles is of the order of 1 pound force per square foot (lbf/ft^2) or less, it is clear that sustained level or climbing flight above that altitude will require centrifugal forces and orbital speeds. Therefore, the problems and requirements of powered flight in the upper atmosphere are identical to those of orbital flight. These orbital vehicles, whether satelloids, maneuverable satellites, or excraft (air-breathing satelloids), will require a propulsion system capable (a) of overcoming aerodynamic drag (which remains significant up to about 130 miles) and geomagnetic drag; and (b) of effecting certain orbital changes or maneuvers.

With present techniques, an orbital vehicle capable of meeting these requirements will need large amounts of propulsive fluid (i.e., propellant or expellant) lifted to orbit even if its propulsion system is capable of high specific impulse. Up to now, the only power plants receiving serious consideration for orbital propulsion applications have been rockets of the chemical, nuclear, or electrical type. Yet the advantages of air-breathing cycles (e.g., greater range and endurance, smaller size of vehicles, economy, etc.) are numerous. The main problem connected with air-breathing orbital propulsion is how to impart sufficient energy to the inlet stream of air to overcome the drag associated with scooping this air.

Thus, chemical reactions do not supply enough energy to overcome the drag of orbital air-breathing vehicles (burning 100 gms of air with hydrogen furnishes only 4.3×10^{12} ergs whereas the stagnation energy of 100 gms of air scooped at orbital speeds is 3.2×10^{13} ergs) and nuclear-heating power plants for air-breathing propulsion require excessively high wall temperatures (of the order of 40,000 K).

These limitations of air-breathing orbital propulsion can be lifted by use of electrical air-breathing propulsion cycles. The electrical ramjet, especially with magnetogasdynamic acceleration of the inhaled air is one promising solution which provides a method of increasing the stagnation enthalpy of the scooped air beyond the limits imposed by chemical reactions and metallurgy.[1-7]

This article will discuss some of the merits and design considerations of magnetohydrodynamic propulsion systems for satellites.

Solution of the problems of orbital air-breathing propulsion will make it possible to operate a propulsive fluid accumulator (PROFAC) for collecting air in low-

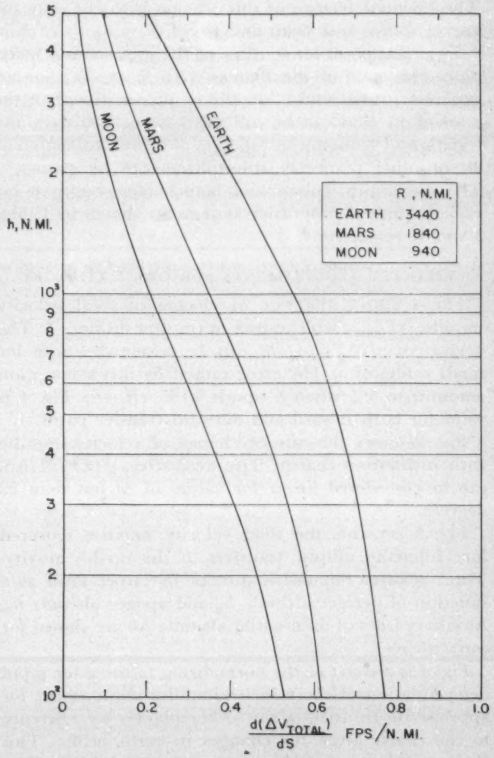


Fig. 1. Iso-orbital transfer, double-impulse single-cycle 5% error when $S=0.187(R_o+h)$.

A special article recommended for publication by the Aero-Space Transportation Committee.

S. T. Demetriades is head, Space Propulsion Laboratory, NORAIR Division, Northrop Corporation, Hawthorne, Calif.

Table I. Mechanical Energy Required by Propulsion System of Each Kind For Given Mission

Kind of Propulsion System	Mechanical Energy $= \int_0^V \vec{F} \cdot \vec{dL}$	ΔE_{reqo} Energy per Gram of Payload in Orbit	ΔE_{reqe} Energy per Gram of Payload to Escape
First Kind: (M_iE_i)	$E_I \geq \int_0^V MVdV \geq M_e u_e^2 \left[1 - \left(1 + \frac{V}{u_e}\right) e^{-V/u_e}\right]$	1.5×10^{13} ergs/gm (Vanguard) 1.0×10^{12} ergs/gm (Modern)	1.1×10^{12} ergs/gm (Modern)
Second Kind: (M_eE_i) Constant Mass (M_p)	$E_{II} \geq \int_0^V M_p V dV = \frac{1}{2} M_p V^2$		
Constant Velocity (Profac)	$E_{II} \geq \int_{M_p}^{M} (\frac{1}{2}\rho A V_e^2) dL = \int_{M_p}^{M} \frac{1}{2} V_e^2 dM = \frac{1}{2} V_e^2 (M - M_p)$	3.2×10^{11} ergs/gm (Stagnation)	1.2×10^{11} ergs/gm (From Profac in orbit)
Third Kind: (M_iE_e)	$E_{III} \geq M_e u_e^2 \left[1 - \left(1 + \frac{V}{u_e}\right) e^{-V/u_e}\right]$ u_e = unlimited since energy external	1.0×10^{12} ergs/gm	1.1×10^{12} ergs/gm
Fourth Kind: (M_eE_e) (Constant Mass)	$E_{IV} \geq \int_0^V M_p \frac{dV}{dt} \cdot dL = \frac{1}{2} M_p V^2$	3.2×10^{11} ergs/gm	6.4×10^{11} ergs/gm

With present efficiencies: ΔE = energy required per unit mass in orbit.

ΔE Invested Nuclear Rocket $> \Delta E$ Invested Profac $> \Delta E$ Thermal Profac $> \Delta E$ Thermal Rocket $> \Delta E$ reqo $> \Delta E$ Stagnation

Mission defined by payload and final velocity.
Integration of work equation carried out on velocity plane.
Kind of propulsion system given by morphological matrix $\{Mj\}$ $[Ej]$ where M = Reaction Mass.
E = Energy, $j = i,e$, i = Internal, e = External

altitude (about 62 miles) orbit for refueling purposes. The essential feature of this scheme is to lift only the energy source into orbit and to collect propulsive fluid (air) at that point for continuing the journey into space. Since the mass of the Profac vehicle (power source, generator, inlet, tanks, cryopump, etc.) is less than the mass of air that can be collected in say, 100 days, the logistic and economic advantages of orbital collection of air or other planetary atmospheres can be great.[3, 5-7] The mechanical energy and launch mass required for various kinds of propulsion systems are shown in Tables I and II respectively.

VELOCITY REQUIREMENTS FOR ORBIT CHANGES

Fig. 1 shows the rate of change of total velocity impulse ΔV_{total}, with respect to transfer distance S. The derivative, $d(\Delta V_{total})/dS$, can be assumed linear for small values of S. The error caused by this assumption amounts to 5% when S equals 0.187 (R_0+h). Fig. 1 is valid for both inward and outward transfer paths.

Fig. 2 shows the rate of change of velocity impulse with inclination change. The derivative, $d(\Delta V)/d(\Delta i)$, can be considered linear for values of Δi less than 20 degrees.

Fig. 3 presents the total velocity impulse required for Hohmann elliptic transfers in the earth's gravity. Total velocity impulse is plotted in carpet form as a function of perigee altitude h_p and apogee altitude h_a. Auxiliary lines of differential altitude Δh are shown for convenience.

Fig. 4 is a chart of the normalizing factor η for rapid determination of the velocity impulse requirement for appropriate transfers about other planets by reference to the charts given for changes in earth orbits. This factor applies to iso-orbital transfers and orbit inclination changes. It does not apply to interorbital transfers.

ION VS. PLASMA PROPULSION SYSTEMS

The power P required to overcome the drag of an air-breathing orbital vehicle per unit inlet area A is given by

$$\frac{P}{A} \approx \rho V \left[2.26 \times 10^4 (\alpha/f) + 1.39 \times 10^4 \left(\phi C_{Dw} \frac{A_w}{A}\right)\left(0.25 \frac{A_w}{A} C_{Dw} + 1\right)\right], \text{ kw/ft}^2 \quad (1)$$

where ρ is the ambient density in pounds mass per cubic foot (lbm/ft^3), V is the orbital velocity in feet per second (ft/sec), α is the degree of ionization, f is the fraction of the total power input into the ionization device which is effective in producing ions (usually about 10% for air), ϕ is the number which multiplies the exhaust power to give the total power input into the accelerator ($P_{acc} = (1/2)\dot{m}\phi V_4^2$ where $\dot{m}$ is the mass rate of flow and V_4 is the exhaust velocity; ϕ is usually between 2 and 5), C_{Dw} is the skin-friction drag coefficient referred to A_w, the wall area in ft^2, and A is the inlet area in ft^2. For flight at 62 miles, $C_{Dw} = 0.05$ and $A_w/A = 10$. Then for an ion propulsion system with $\phi = 2$,

$$\left(\frac{P}{A}\right)_{ion} \approx \rho V[2.26\times10^5 + 1.56\times10^4] = 270 \text{ kw/ft}^2 \text{ at 62 miles}, \quad (2)$$

and for a plasma propulsion system with $\phi = 4$, where only a fraction of the stream is ionized, say 1%

$$\left(\frac{P}{A}\right)_{plasma} \approx \rho V[2.26\times10^3 + 3.14\times10^4] = 40 \text{ kw/ft}^2 \text{ at 62 miles}. \quad (3)$$

It is clear that with present techniques the ion propulsion system requires almost an order of magnitude more power than the plasma system. This excessive

power requirement is a consequence of the need to ionize a large percentage of the inlet stream for ion propulsion. This ionization power is large compared to the power required for electrostatic acceleration at the low exhaust speeds involved in orbital propulsion (up to 52,000 ft/sec) and therefore makes a significant contribution to the total power required. There are other important reasons why ion propulsion systems are not efficient at these low exhaust speeds; Forrester and Speiser give most of them.[8]

DESIGN CONSIDERATIONS FOR MGD ORBITAL RAMJET

THERE ARE FOUR IMPORTANT PROBLEM AREAS connected with the design of a magnetogasdynamic (MGD) orbital ramjet: inlet, gas collector, plasma generator, and MGD driver (engine) design.

It is evident that the inlet has to be designed for molecular flow and the gas must be compressed by means other than mere ram compression. Before the air is captured, most of its stagnation energy will have to be dissipated by radiation from the walls of a dissipative inlet. A design procedure for a dissipative inlet was given elsewhere.[9] Since the volumetric flow rate will be extremely high, a cryopump has been designed to collect the air by freezing it on surfaces cooled by helium to 30 K or lower. The cycle and other characteristics of this cryopump will be discussed. Other methods for collecting air in orbit are under investigation. For relatively low-altitude operation (about 105 km) a rotary precompressor may be required after the dissipative inlet and before the liquifier.[1]

The plasma generator can take the form of any one of several available devices (arc plasmajet, glow discharge, magnetron, etc.) any one of which raises the conductivity of air sufficiently to pass the required currents. If necessary, seeding by small amounts (0.1%) of sodium or potassium can be used to keep the conductivity high.

Some theoretical and experimental results on an MGD driver for air and argon will be given.

DESIGN OF CRYOPUMP FOR AIR COLLECTION

THE AIR INTERCEPTED at orbital speeds is slowed down and cooled at the inlet and the inlet walls radiate most of the stagnation energy of the air stream to the surroundings. Thus, at the entrance of the cryopump the air is at an estimated temperature of 1,100 K and a pressure of 10^{-6} atmos (atmospheres). In the cryopump, this air is passed through a series of heat exchangers and eventually frozen. The air pressure at the cryopump entrance is well below the triple point of the oxygen and nitrogen gas, and, therefore, no liquid phase will appear. The temperature at which the air is frozen is approximately 30 K. The freezing process will provide adequate pumping action because the vapor pressure of the nitrogen is 7×10^{-8} atmos at the freezing temperature of 30 K.

The preliminary design of a cryogenic system for collecting air in orbit at low pressures and high mass flow rates by freezing (i.e., a cryopump) follows. This system is quite similar to a reversed Brayton cycle with heat regeneration. The differences consist of (a) the use of a bypass turbine in addition to the main turbine, and (b) the approximation of isothermal compression by use of seven stages of compressor with intercooling as opposed to the isentropic compression of Brayton's cycle.

Helium is selected as the working fluid for its low

Table II. Launch Mass Required by Propulsion System of Each Kind For a Given Mission

Kind of Propulsion System	Launch Mass from Earth Surface	Launch Mass Required to Escape		Launch Mass Required for Lunar Landing and Return	
		Chemical	Nuclear	Chemical -Nuclear	Nuclear
First Kind: (M_iE_i)	$M_o = M_p \prod_{n=1}^{l} r_n \cdot \prod_{n=l+1}^{m} r_n$	(4 stages) $\sim 100 M_p$	25-30M_p	235M_p	70M_p
Second Kind: (M_eE_i) Orbital Refueling (Hybrid with First Kind)	$M_o = (M_p + M_{SY,\,\mathrm{dry}}) \prod_{n=1}^{l} r_n$ $M_o = M_p \left(1 + \frac{\alpha}{\Sigma M}\right) \prod_{n=1}^{l} r_n$	Chemical Booster	Nuclear Booster	Chemical Booster	Nuclear Booster
With PROFAC in Orbit (Hybrid with First Kind):	$M_o \approx M_p \prod_{n=1}^{l} r_n$	35M_p	<17M_p	35-52M_p	17-25M_p
Third Kind: (M_iE_e)	$M_o = M_p \prod_{n=1}^{l} r_n \cdot \prod_{n=l+1}^{m} r_n$	—		—	
Fourth Kind: (M_eE_e)	$M_o = M_p + M_{\mathrm{shield}}$	$\sim 2M_p$		$\sim 2M_p$	

With orbital refueling, hybrid systems of the first and second kind can accomplish most missions with launch mass required to orbit the payload.
M_o = Launch Mass; M_p = Payload Mass; $r_n = M_{on}/M_{pn}$ = Payload Ratio, l = number of stages required to orbit,
m = total number of stages to accomplish mission; $\alpha = M_{SY,\,\mathrm{dry}}/M_p$;
$M_{SY,\,\mathrm{dry}}$ = Mass of Dry Orbital Refueling System Made up of Orbital Vehicle, PROFAC and Space Vehicle, ΣM = Number of Missions Using PROFAC System Kind of Propulsion System Given by Morphological Matrix $\{Mj\}$ $[Ej]$, where M = Reaction Mass,
E = Energy; j = i,e; i = Internal, e = External.

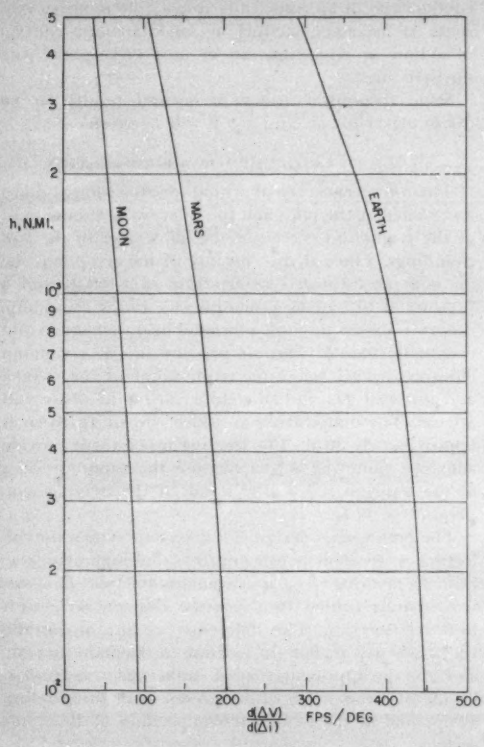


Fig. 2. Circular orbit inclination changes; single impulse $0 \leqslant i \leqslant 20$ degrees.

liquefaction temperature. As shown in the T-S diagram, Fig. 5, path *a-c* is the heat absorption cycle, path *c-d* is the compression cycle, and paths *d-e* and *e-f* are the heat regeneration cycle. Heat flows from the high pressure and temperature helium to the low pressure and temperature helium. Paths *e-b*, and *f-a* are the isentropic expansion cycles, with path *e-b* called the bypass to distinguish it from the main path. These modifications to the Brayton cycle were devised to increase the efficiency and decrease the size of the system. This equipment was designed to freeze one gram of air per second. The final size of the equipment may be scaled up accordingly. A total of 6 gm of helium is required of which 0.7 gm is bypassed. The lower temperature is set at 10 K while the high temperature (which is the temperature of the heat rejector or radiator) is set at 870 K (1,000 F).

The requirements of radiator area, heat rejection rate, and helium flow rate per square foot of the inlet area are presented as a function of the altitude in Fig. 6. These requirements are computed on the basis of the inlet airflow rate also shown in Fig. 6.

TWO-DIMENSIONAL MGD FLOW EQUATIONS

The usual equations of magnetogasdynamics may be simplified by assuming that the velocity vector is given by

$$U = (U_x, 0, U_z) \tag{4}$$

while the electric field is given by

$$E = (0, 0, E_z) \tag{5}$$

and the magnetic induction, which will now be called "magnetic field," is given by

$$B = (B_x, -B_y, 0). \tag{6}$$

Here E_z and B_y are the imposed (external) fields in the control of the designer and U_z, B_x are the induced components of the velocity and magnetic field. The equations of continuity, state, momentum, and energy as well as Maxwell's four equations and Ohm's law for this model were given previously.[10] Some interesting relationships are

$$\mathbf{J}\times\mathbf{B} = \sigma[(E_z - U_z B_y)B_y\mathbf{i} + (E_z - U_z B_y)B_x\mathbf{j} - U_z(B_y^2 + B_x^2)\mathbf{k}], \tag{7}$$

(the ponderomotive force per unit volume) and

$$\mu\mathbf{J} = \nabla \times \mathbf{B} = \mu\sigma[U_z B_y\mathbf{i} + U_z B_x\mathbf{j} + (E_z - U_z B_y)\mathbf{k}]$$

$$= \frac{\partial B_y}{\partial z}\mathbf{i} + \frac{\partial B_x}{\partial z}\mathbf{j} - \left(\frac{\partial B_y}{\partial x} + \frac{\partial B_x}{\partial y}\right)\mathbf{k} \tag{8}$$

In these equations σ = conductivity, μ = permeability, J = current density.

The MGD equations can be solved under appropriate boundary conditions and assumptions to give the velocity, temperature, and pressure distributions. Thus, for constant area flow when only **i** components are important in the momentum equation while the velocity, electric field, and magnetic field components are given by $(U, 0, 0)$, $(0, 0, E_o)$ and $(B_x, -B, 0)$ respectively, where E_o = constant, we obtain

1. *Isothermal Conditions,* $\partial T/\partial x = 0$

$$U^4 = 4\sigma RTAE_o^2 x/\dot{m} + U_o^4, \tag{9}$$

$$B = [1 - (RT)/U^2]\,(E_o/U). \tag{10}$$

2. *Isobaric Conditions,* $\partial P/\partial x = 0$

$$(U^3 - U_o^3) - 3a(U^2 - U_o^2) + 3a^2(U - U_o) = 3aA\sigma E_o^2 x/\dot{m}, \tag{11}$$

$$B = E_o/(a + U),\ a = C_p PA/(R\dot{m}) \tag{12}$$

Equations 10 and 12 prescribe the imposed magnetic field when the initial magnetic Reynolds number is small and $U/U_o < 4$. Even then these solutions are not necessarily consistent with equation 8. In fact, the a priori assumption of equations 4 to 6 or any other model short of the complete 3-dimensional model is of questionable validity.

THE (U_1, B_2, E_3)-DIMENSIONAL MGD PROBLEM

When the components of the velocity, induction, and electric field are $(U, 0, 0)$, $(0, -B, 0)$ and $(0, 0, E_o)$ respectively, where E_o is constant, the usual constant-area magnetogasdynamic (MGD) equations reduce to

$$P = \rho RT, \tag{13}$$

$$\frac{\dot{m}}{A} = \rho U, \tag{14}$$

$$P + \rho U^2 + B^2/2\mu = C_1 = \text{constant}, \tag{15}$$

$$\frac{\dot{m}}{A}\left[\frac{\gamma}{\gamma-1}\frac{P}{}+\frac{1}{2}U^2\right]+\frac{E_o B}{\mu} = C_2 = \text{constant}, \tag{16}$$

and

$$\frac{dB}{dx} = -\mu\sigma(E_o - UB), \tag{17}$$

where P = pressure, ρ = density, T = temperature, A = channel cross-sectional area, $\dot{m}$ = mass flow rate, R = gas constant, γ = ratio of specific heats, μ = magnetic permeability, and σ = conductivity. It is clear from these five equations that the assumption that A, E_o, σ, γ, and R are all known constants, is sufficient to determine the five functions $B(x)$, $\rho(x)$, $U(x)$, $T(x)$, and $P(x)$, provided the values of C_1 and C_2 are known in terms of the initial values of the quantities B, ρ, U, T, and P. Thus the change of all five of these variables with x may be determined if their initial values are known.

To determine these functions, note that the first four equations yield U as a function of B only, given by

$$U = -a(B^2 - b) \pm \{a^2(B^2 - b)^2 - c(d - B)\}^{1/2}, \tag{18}$$

where the "+" sign if taken for supersonic and the "−" sign for subsonic flows and $a = \gamma/[(\gamma+1)2\mu\rho U]$, $b = 2\mu C_1$, $c = 2E_o(\gamma-1)/[(\gamma+1)\mu\rho U]$ and $d = C_2\mu/E_o$.

Then the value of B may be determined by expanding B in a Maclaurin series in terms of x and using equation 17 to obtain the coefficients. Thus

$$B = B_o + \left(\frac{dB}{dx}\right)_o x + \left(\frac{d^2B}{dx^2}\right)_o \frac{x^2}{2} + \left(\frac{d^3B}{dx^3}\right)_o \frac{x^3}{6} + \cdots \tag{19}$$

where B_o is the initial value of B at $x = 0$, and

$$\left(\frac{dB}{dx}\right)_o = -\mu\sigma(E_o - U_oB_o), \left(\frac{d^2B}{dx^2}\right)_o = \mu\sigma\left(U\frac{dB}{dx} + B\frac{dU}{dx}\right)_o, \tag{20}$$

and so forth. Note that dU/dx, d^2U/dx^2, etc. may be written

$$\frac{dU}{dx} = \frac{dU}{dB}\frac{dB}{dx}, \frac{d^2U}{dx^2} = \left(\frac{dB}{dx}\right)^2\frac{d^2U}{dB^2} + \frac{dU}{dB}\frac{d^2B}{dx^2}, \tag{21}$$

and so forth. The derivatives dU/dB, d^2U/dB^2, etc., may be computed from the expression of U in terms of B given in equation 21. In most applications, the coefficients of this series are of the order of unity or less and $x < 1$.

This solution of the MGD equations for (U_1, B_2, E_3)-dimensional flow is consistent; i.e., it does not rest on any redundant assumptions, and does not violate any of Maxwell's equations. It must be emphasized, however, that the possibility of (U_1, B_2, E_3)-dimensional flow must be established experimentally.

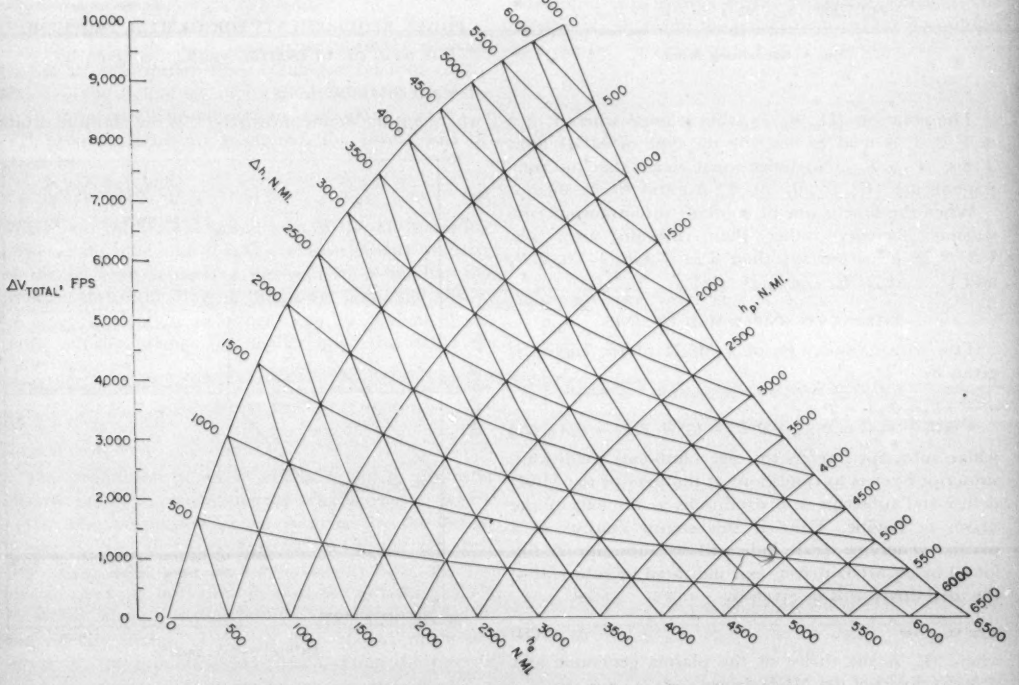


Fig. 3. Coplanar interorbital transfer, double-impulse Hohmann-ellipse earth gravity.

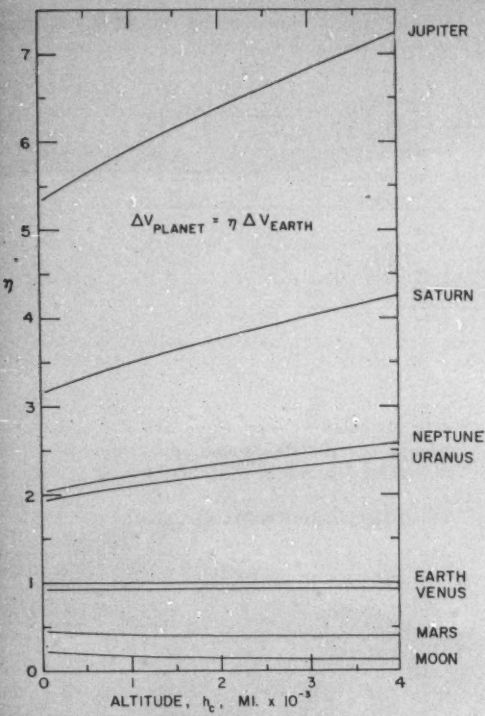


Fig. 4. Normalizing factor.

The notation (U_i, B_j, E_k)-dimensional where $i, j, k = 1, 2, 3$, is used to describe the type of MGD flow. Thus, $(U_{1,2}, B_{2,3}, E_2)$-dimensional means that the components are $(U_x, U_y, 0)$, $(0, B_y, B_z)$ and $(0, E_y, 0)$.

When the flow is one of constant instantaneous conversion efficiency rather than constant area, i.e., $UB/E_\theta = \alpha =$ constant, then $B = -\mu\sigma E_\theta(1-\alpha)x + B_\theta$ and $U = \alpha E_\theta / \{B_\theta - \mu\sigma E_\theta(1-\alpha)x\}$.

THRUST OF SIMPLE MGD ENGINES

THE TOTAL THRUST Θ_t of a MGD rocket engine is given by

$$\Theta_t = \dot{m}U_4 + P_4A_4 - P_1A_1$$
$$= \dot{m}U_2 + P_2A_2 - P_1A_1 + \dot{m}(U_4 - U_2) + P_4A_4 - P_2A_2, \quad (22)$$

where subscript 1 refers to inlet (ambient) conditions, subscript 2 refers to conditions at the inlet of the MGD driver and subscript 4 to conditions at the exit of the driver or engine. Thus, if this engine consists of a plasma generator (exit indicated by subscript 2) followed by an MGD driver, exit indicated by subscript 4, the total thrust will be given by

$$\Theta_t = \Theta_{pg} + \Theta \quad (23)$$

where Θ_{pg} is the thrust of the plasma generator and Θ is the thrust of the MGD driver.

It can be shown that the thrust of the rectangular MGD driver (crossed fields) without inlet losses or cross-sectional area changes and without a nozzle or end effects is equal to the reaction of the coils; i.e.,

$$\Theta = \dot{m}(U_4 - U_2) + P_4A_4 - P_2A_2$$
$$= A\sigma B_\theta\left(E_\theta L - B_\theta \int_0^L U_x dx\right) \quad (24)$$

where L is the length of the driver along x (or i), A is the cross-sectional area (constant along i) and E_θ and B_θ are imposed externally and adjusted to remain constant. Equation 24 also gives the thrust of a simple MGD ramjet (again with negligible inlet and exit effects).

It can now be shown that if E_θ is constant, $B_z = 0$ and $B_y = B_\theta =$ constant,

$$\partial B_x/\partial y = dB_x/dy, \quad (25)$$

and the change of B_x with respect to y is given by

$$dB_x/dy = -\mu\sigma(E_\theta - U_xB_\theta). \quad (26)$$

Therefore $U_x = U_i =$ constant (since U_x was assumed independent of y) and the thrust is due to a pressure increase.

Then

$$\Theta = A\sigma B_\theta L(E_\theta - U_iB_\theta). \quad (27)$$

This is a convenient relationship for establishing the order of magnitude of thrust of a simple rectangular MGD driver.

POWER REQUIREMENTS FOR ORBITAL PROPULSION

THE DRAG OF AN ORBITAL VEHICLE is given by

$$D = \rho V^2 (0.5A_wC_{Dw} + A_i) \quad (28)$$

where ρ is the ambient density, V is the absolute orbital

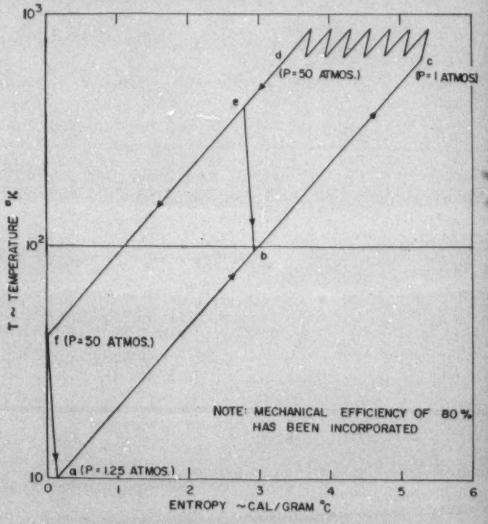


Fig. 5. Temperature vs. entropy for cryogenic system.

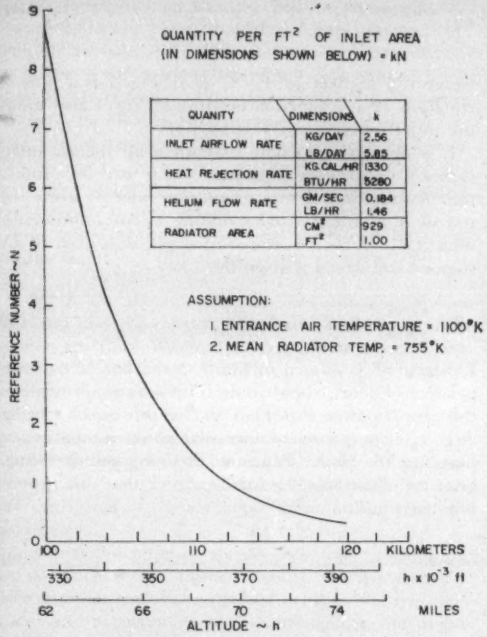

QUANTITY PER FT² OF INLET AREA
(IN DIMENSIONS SHOWN BELOW) = kN
QUANITY | DIMENSIONS | k
INLET AIRFLOW RATE | KG/DAY | 2.56
LB/DAY | 5.65
HEAT REJECTION RATE | KG.CAL/HR | 1330
BTU/HR | 5280
HELIUM FLOW RATE | GM/SEC | 0.184
LB/HR | 1.46
RADIATOR AREA | CM² | 929
FT² | 1.00
ASSUMPTION:
1. ENTRANCE AIR TEMPERATURE = 1100°K
2. MEAN RADIATOR TEMP. = 755°K
REFERENCE NUMBER ~ N
KILOMETERS
h x 10⁻³ ft
MILES
ALTITUDE ~ h

Fig. 6. Inlet airflow rate, heat rejection rate, helium flow rate, and radiator area vs. altitude.

velocity, A_w is the wall area exposed to the airflow, C_{Dw} is an appropriate drag coefficient referred to A_w and A_i is the area of an inlet which effectively stops the air it intercepts with respect to the vehicle.

If pressure terms are neglected, the thrust will be given by

$$T = \rho A V(V_4 - V) \tag{29}$$

where A is the cross-sectional area of the air-breathing power plant inlet and V_4 is the relative exhaust velocity of the jet with respect to the vehicle. Note that the pressure thrust (or drag) of the power plant can always be accounted for by defining V_4 as an equivalent exhaust velocity, greater (or smaller) than the actual exhaust velocity.

The total inlet area A_{ti} in this case would be given by

$$A_{ti} = A + A_i. \tag{30}$$

The propulsion power P will be equal to the total electric power P_E multiplied by an efficiency f (where $f<1$). The propulsion power is given by the thrust power P_T (i.e., the work done by the thrust per unit time, $P_T = TV$) plus the kinetic energy lost with the ejected mass per unit time P_E (i.e., the exhaust loss, $P_E = \dot{m}c^2/2$, where c is the absolute velocity of the jet or the velocity change of the jet with respect to an observer on the ground, $c = V_4 - V$). Then the electric power required will be given by

$$P_E \cdot f = \rho A V(V_4 - V)V + \tfrac{1}{2}\rho A V(V_4 - V)^2 \tag{31}$$

or

$$P_E = \tfrac{1}{2} A V \phi (V_4^2 - V^2)\rho \tag{32}$$

where $\phi = 1/f$.

Then the power required for orbital propulsion is given by

$$P_E = \frac{0.5\rho V^3 \phi}{A} \tag{33}$$

$$\left[A_i A_w C_{Dw} + 2A_i A + A_i^2 + A\left\{0.25\frac{A_w^2 C_{Dw}^2}{A} + A_w C_{Dw}\right\}\right]$$

If the right-hand side of the last equation is multiplied and divided by A_i^2, we obtain

$$P_E = 0.5\rho V^3 \phi \frac{A_i^2}{A}$$

$$\left[\left(\frac{0.5A_w C_{Dw}}{A_i} + 1\right) + \frac{2A}{A_i}\right]\left(\frac{0.5A_w C_{Dw}}{A_i} + 1\right). \tag{34}$$

The last equation gives the power required for orbital propulsion if *some* of the total airflow intercepted by A_{ti}, namely the flow through A_i, is stopped (or captured and stored) and the rest, namely the flow through A, is used for propulsion.

When $A_i = 0$; i.e., when none of the intercepted fluid is stopped with respect to the vehicle or stored in the vehicle, $A_{ti} = A$ and the power required for propulsion is given by

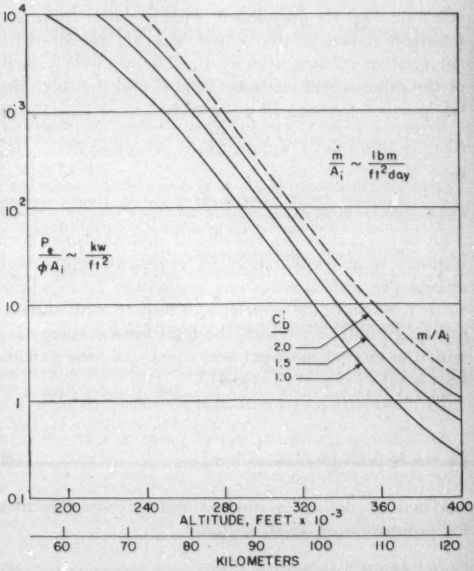


Fig. 7. Power requirements and collection rate vs. altitude.

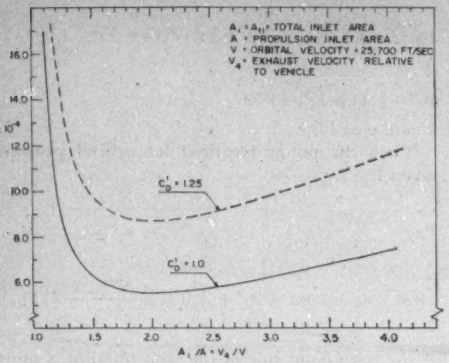


Fig. 8. Power required per pound collected.

$$P_E = 0.5\rho V^3 \phi C_{Dw} A_w \left(0.25 \frac{A_w}{A} C_{Dw} + 1\right). \tag{35}$$

The last equation was used in deriving equation 1.

When all the intercepted air is stopped with respect to the vehicle and *some* is subsequently used for propulsion, the total inlet area is equal to the stopping area A_i or

$$A_{ti} = A_i \tag{36}$$

and the above equations no longer hold since the thrust must be written

$$T = \rho A V \cdot V_4 \tag{37}$$

where A is that portion of the total inlet which intercepts air used for propulsion. This air, after coming to rest with respect to the vehicle, is again accelerated to the relative exhaust velocity V_4. The absolute velocity of the exhaust will again be $V_4 - V$ and the total electric power required will be given by

$$P_E \cdot f = \rho A V \cdot V_4 \cdot V + \tfrac{1}{2} \rho A V (V_4 - V)^2 - \tfrac{1}{2} \rho A V^3 \tag{38}$$

or

$$P_E = \tfrac{1}{2} \rho A V \cdot \phi \cdot V_4^2 \tag{39}$$

The last term on the right-hand side of equation 38 requires some explanation. It represents the kinetic energy per unit time of the propellant or expellant, while it is still in the vehicle, with respect to an observer on the ground. Therefore, the total kinetic energy *lost* with the ejected mass per unit time (i.e., the exhaust loss) is $\frac{1}{2}\rho A V(V_4 - V)^2 - \frac{1}{2}\rho A V^3$.

By eliminating V_4 we obtain

$$P_E = 0.5\phi \ (\rho V^3) \left(0.5 C_{Dw} \frac{A_w}{A_i} + 1\right)^2 \frac{A_i^2}{A} \tag{40}$$

When all the air is stopped and subsequently used for propulsion, $A_{ti} = A_i = A$ and

$$P_E = 0.5\phi \ (\rho V^3) \ (C'_D)^2 A_i \tag{41}$$

or

$$\frac{P_E}{\phi A_i} = 0.2105 \times 10^{-4} \ (\rho V^3) \ (C'_D)^2, \frac{\text{kw}}{\text{ft}^2}, \tag{42}$$

where $C'_D = (0.5 C_{Dw} \ A_w/A_i + 1)$. Fig. 7 is a plot of equation 42 as a function of altitude. Fig. 7 also shows the collection rate per unit area ρV.

It is interesting to note that when all the air intercepted is stopped and only part of it is used for propulsion (corresponding to a propulsion inlet A) while the rest of it is stored (corresponding to an accumulator inlet $A_i - A$), the power required per unit mass of air stopped and stored is given by

$$\Delta P = \frac{P_E \cdot \Delta t}{\Delta m \cdot \phi} = 0.5 V^2 \ (C'_D)^2 \frac{(A_i/A)^2}{(A_i/A) - 1}. \tag{43}$$

Equation 43 is plotted in Fig. 8. Note that ΔP is independent of density or altitude. This expression neglects the actual power expended in the process of storing (e.g., cryopump power) since that power is small compared to the power expended to overcome the drag, given by equation 43. It can be shown that this expression has a minimum at

$$\frac{A_i}{A} = 2. \tag{44}$$

Since

$$V_4 = (C'_D) \frac{A_i}{A} V$$

for $C'_D = 1$, $V_4 = 2V$. Then the accumulator area is equal to the propulsion area A.

Operation at exhaust velocities lower than $2V$ will be necessary due to state-of-the-art considerations. As shown in Fig. 8, the resulting penalty in required power is not significant until $V_4 < 1.4\ V$.

The factor φ is approximately 15 for the isotachous driver[10] because of high thermal losses (the exit temperature in a typical example is approximately 90,000 K). Most of this energy can be recovered and eventually values of φ of the order of 2-6 are expected (not necessarily by isotachous operation).

EXPERIMENTAL MGD ENGINE FOR AIR

An electromagnet capable of 12,000 gauss with a gap of approximately 1 inch was suspended on a balance. The balance was enclosed in a vacuum tank where the pressure was maintained at approximately 2,000 microns while a nitrogen plasma jet from an arc source was exhausting in it. The plasma jet was directed between the pole pieces of the magnet. The external electric field was provided by a pair of tungsten electrodes. Various configurations and materials were tested. The electrodes were an integral part of the magnet-balance system and the influence of all leads and other lines on the balance was compensated. "Frictionless" mercury pots were used to connect the electrodes to the rigid power lines. The balance-magnet-electrode assembly was approximately 1 inch from the

end of the plasma jet nozzle. The free jet of plasma, of approximately 1-inch diameter, barely touched the electrode surfaces. Electrode cooling was accomplished by means of an integral aluminum heat sink. Fig. 9 shows an MGD engine of the type tested on the balance.

When the electric current and magnetic induction were turned on while the plasma jet was streaming through the space confined by the pole pieces and the electrodes, a definite reaction (either thrust or drag) was detected by the balance.

The following qualitative tests were used to establish the nature of this effect:

1. With the current (due to field emission apparently) on and the magnet off there was no detectable balance reaction. When the magnet was switched on there was a definite reaction (thrust or drag, depending on the polarity of the magnetic field).
2. Reversing the polarity of the magnet caused the balance to tip in the reverse direction.
3. As the magnetic field was increased the current passing through the electrodes was decreased until at a certain value of the magnetic field the discharge was extinguished.
4. When the imposed electric field was switched off (i.e. no discharge or applied electric field between the electrodes) an emf was generated between the two electrodes and a current flowed in the circuit (heating a resistance).
5. The discharge between the electrodes of the MGD driver becomes thicker (and more diffuse) as the current density, amperes per square inch (amps/in^2), is increased.
6. An increase in the electric current caused an increase in the thrust.

The quantitative results include the simultaneous measurement on a synchronized 5-channel recorder of the thrust or drag (two strain gages of appropriate sensitivity), magnet-coil current (calibration curves give the induction in the gap), electrode current and voltage across the electrodes.

The electrode current was varied from 10 amps/in^2 to 1,500 amps/in^2. (When molybdenum anodes were used there was considerable melting of the anode at the 1,500-amps/in^2 level.) The electrode potential was varied from 24 volts per inch (volts/in) to 360 volts/in. Typical measurements were: thrust (identical on both gages): 0.15 lbf; electrode current: 150 amps/in^2; electric field strength: 48 volts/in–96 volts/in; electrode area: 1 square inch; electrode gap: $\backsim$ 1 inch; magnetic induction: 0.2 weber per square meter; volume of MGD driver: 1 cubic inch (approximate); conductivity: 1–2 mhos per centimeter (measured 6 inches from exit of plasma generator).

On the basis of these measurements the computed thrust is

$$\Theta = \sigma(E_o - UB_o) \cdot h \cdot w \cdot L \cdot B_o = 0.16 \text{ lbf}, \quad (45)$$

where σ (E_θ — UB_θ) = current per unit area = 150 amps/in^2; h = height of driver (electrode gap) = 1 inch; w = width of driver or magnet gap = 1 inch; L = length of driver (equal to the length of pole pieces or electrodes) = 1 inch; B_o = applied magnetic induction = 0.2 weber per square meter. The rectangular configuration of the MGD section may be varied from 1 by 1 by 1 inches to 1 by 1 by 3 inches (width times height times length). The agreement between the measured (0.15 lbf) and computed (0.16 lbf) thrust is excellent. Over-all efficiencies of the order of 30% were attained.

Fig. 9. Experimental model of MGD engine for air.

REFERENCES

1. A Novel System for Space Flight Using a Propulsive Fluid Accumulator, S. T. Demetriades. NB-59-161, Norair Division, Northrop Corporation, Hawthorne, Calif., ASTIA Doc. AD 226-086, Dec. 20, 1958; also *Journal* British Interplanetary Society, London, England, vol. 17, no. 5, Sept.-Oct. 1959, pp. 114-19.
2. Comments on Photochemistry of the Upper Atmosphere as a Source of Propulsive Power, *Journal* American Rocket Society, New York, N. Y. May 1959, p. 375; also The Use of Planetary Atmospheres for Propulsion, S. T. Demetriades, C. B. Kretschmer. *Proceedings*, Fourth Annual Meeting of American Astronautical Society, AAS preprint no. 57-46, Jan. 31, 1958; also AFOSR TN 58-229, ASTIA AD 154-229, March 4, 1958.
3. Magnetogasdynamic Acceleration of Flowing Gases and Applications, S. T. Demetriades. NB-59-153, Norair Division, Northrop Corporation; also ASTIA document AD 229-672, March 23, 1959.
4. New Propulsion Concepts, S. T. Demetriades. NB-59-176, *Ibid.*; also ASTIA document AD 229-087, July 1, 1959.
5. Orbital Propulsion System for Space Maneuvering (PROFAC), S. T. Demetriades. *Astronautical Sciences Review*, vol. 1, no. 4, Oct.-Dec., 1959.
6. Air Scooping Vehicle, F. Berner, M. Camac. Research Report 76, AVCO Everett Research Laboratory, AFBMD TR 59-17, Aug., 1959.
7. Design and Applications of Propulsive Fluid Accumulator Systems, S. T. Demetriades. NB-60-16, Norair Division, Northrop Corporation, Feb. 1960.
8. Cesium Ion Propulsion, A. T. Forrester, R. C. Speiser. *Astronautics*, New York, N. Y., Oct. 1959.
9. Preliminary Study of Propulsive Fluid Accumulator Systems, S. T. Demetriades. Norair Division, Northrop Corporation, ASRL TM 60-7, June 1960; also presented at Eleventh IAF Congress, Stockholm Sweden, Aug. 15-20, 1960 (paper no. 53).
10. Magnetohydrodynamic Orbit Control for Satellites, *Ibid.* ASRL TM 60-6, June 1960; also presented at AIEE Pacific General Meeting, Aug. 8-12, 1960 (CP 60-1087).

Flux Pattern Instrumentation Using Hall Probes

H. HOLLITSCHER

ASSOCIATE MEMBER AIEE

SEARCH COILS are the customary tools for industrial testing of magnetic fields. They have significant drawbacks, since the output is proportional only to changes in magnetic flux, and integration is necessary to obtain flux readings.

Fig. 1. Typical on-site arrangement of test equipment.

The use of the Hall effect for the measurement of magnetic fields has been known for about 80 years. With recent advances in semiconductor technology, advantage has been taken of the enhanced Hall effect in some of these materials to produce commercial Hall probes. They are of very high quality and stability and they produce output signals of 0.3 volt and more. The practical measurement of flux density or flux pattern in magnetic circuits with Hall probes now seems feasible.

Instrumentation was designed and built primarily for the exploration of air-gap flux distribution in rotating machines but can also be used for measurements of any magnetic circuit with air gaps.

Ten Hall probes are used as sensing elements of the magnetic field at ten discrete locations. Auxiliary equipment, such as power supplies for the probes, calibrating milliammeter, shunts, selector switches, etc., are built into a portable unit. A dual-beam oscilloscope and a multichannel recorder are used for the display and recording of the flux traces.

A typical on-site arrangement of the equipment is shown in Fig. 1, where the flux pattern at the interpoles of a 4,500-hp d-c motor was recorded. The probe arrangement of this particular test is shown in Fig. 2. Five probes are mounted in a phenolic laminate bar and the bar is glued to the pole face of an interpole.

Other tests were recently carried out on large waterwheel generators to study the flux swing and oscillation in the air gap under various load conditions. The equipment also was used to detect intermittent short circuits in pole windings of a synchronous motor, which caused severe vibration. Impedance tests of the windings did not produce satisfactory results while flux traces taken under dynamic conditions gave evidence of partial short circuits.

The equipment has the following advantages over the more conventional methods of exploring magnetic fields:

1. Pointwise measurement of flux is possible.
2. The flux density at several points, even in different directions, can be measured simultaneously.
3. Results are obtained directly in flux density and no integration is necessary as with the output of search coils.
4. Any stationary or alternating field can be measured and also such fields where d-c and a-c components are superimposed can be recorded.

With the use of computers, the design of rotating machines can now be refined and calculations be made regarding the magnetic circuit where previously only empirical formulas could be used. This new test equipment should, therefore, prove particularly useful in the test and design of rotating machines and of magnetic circuits in general.

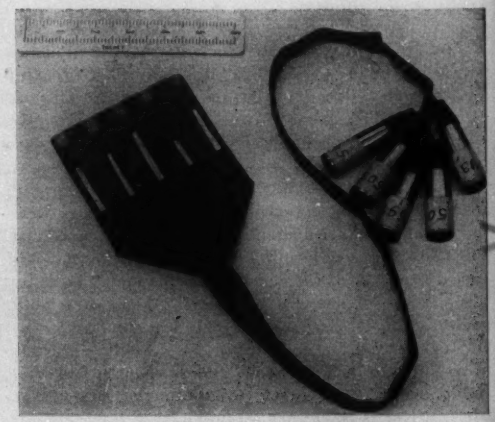


Fig. 2. Probe assembly for interpole flux tests

Digest of paper 60-835, "Magnetic Flux Pattern Instrumentation Using Hall Probes," recommended by the AIEE Special Instruments and Auxiliary Apparatus Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Summer General Meeting, Atlantic City, N. J., June 19-24, 1960. Published in AIEE *Power Apparatus and Systems*, Dec. 1960.

H. Hollitscher is with the Canadian General Electric Company, Ltd., Peterborough, Ont., Canada.

The Effect of Variable Plasma Conductivity on MHD Energy Converter Performance

W. B. COE

C. L. EISEN

The magnetohydrodynamic energy converter provides a means for converting some of the kinetic and thermal energy of a plasma directly into useful electrical work. A performance study of a constant-area channel in which the conductivity of the plasma depends on its local thermodynamic properties is described.

THE CONCEPT of a magnetohydrodynamic (MHD) energy converter presents a means of converting some of the kinetic and thermal energy of a plasma directly into useful electrical work. The principle upon which its operation is based is that of passing a moving plasma through a transverse magnetic field, thereby inducing an emf (electromotive force) in the plasma. By completing the circuit through an external load, a current is then permitted to flow. The analysis of such a device is complicated by the fact that the working fluid is a compressible medium, subject not only to the laws of compressible fluid flow, but to the laws of electromagnetism as well.

The potentialities of the MHD energy converter were investigated by Neuringer[1] who applied the techniques of the calculus of variations to obtain an appropriate set of differential equations governing the conditions under which the maximum amount of useful electric power could be generated. Although the equations he derived are quite general, they can be integrated in closed form only for special cases. One of the special cases to which Neuringer applied these equations and obtained solutions was that of a converter with constant cross-sectional area and with constant plasma electrical conductivity. The results of this study showed that appreciable amounts of energy could be converted into useful electrical work.

A subsequent investigation undertook to obtain solutions to a set of differential equations governing the performance of the MHD converter. The equations were written for a varying channel cross-sectional area and allow the electrical conductivity of the plasma to depend on its local thermodynamic properties. These equations were programmed for numerical solution on an IBM *704* digital computer. The results of the computation permit the investigation of the performance of the converter for other than maximum energy conversion. A preliminary study[2] confined itself to a constant cross-sectional area converter with an assumed constant plasma conductivity.

The present article reports the results of a similar performance study of a constant-area channel in which the electrical conductivity of the plasma is dependent on its local thermodynamic properties.

Essentially full text of conference paper CP60-1028, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

W. B. Coe and C. L. Eisen are with the Republic Aviation Corporation, Farmingdale, N. Y.

This work was sponsored by the U. S. Air Force Office of Scientific Research under contract no. AF49(638)-552, jointly with the Republic Aviation Corporation.

ASSUMPTIONS

THERE ARE a number of assumptions and approximations in the derivation of the equations governing the performance of the MHD energy converter. These include

1. One-dimensional flow, i.e., the fluid dynamical state variables vary in the flow direction only, and not over the cross section.
2. Small magnetic Reynolds number, i.e., any effects on the fluid flow of secondary magnetic fields resulting from the induced current distribution are negligible, either because the secondary magnetic fields are too small, or in the wrong direction to produce appreciable effects.
3. Negligible Hall current, i.e., the induced currents in the flow direction are small compared to those induced in the direction perpendicular to both the flow and to the magnetic fields.
4. The plasma behaves as a perfect gas.
5. The specific heats are constant.
6. The plasma is inviscid and nonheat conducting, so that the only dissipation is electrical.
7. The plasma is electrically neutral, i.e., no space charge sheaths are developed near the conducting walls.
8. There is shock-free supersonic flow.
9. The channel walls are perfect electrical conductors.

EQUATIONS

LET THE FLOW of the plasma through the channel be in the x direction, as shown in the schematic diagram of the converter, Fig. 1. The channel cross-sectional area is given by the product $y(x)z(x)$, where $y(x)$ is the channel height (or electrode spacing) and $z(x)$ is the channel depth, both being prescribed functions of x, subject to the conditions that dy/dx and dz/dx are everywhere sufficiently small as required by the one-dimensional flow approximation. The applied magnetic field, $B(x)$, is in the z direction and is also a prescribed function of x. (Although the results discussed in the next section are for constant channel cross sec-

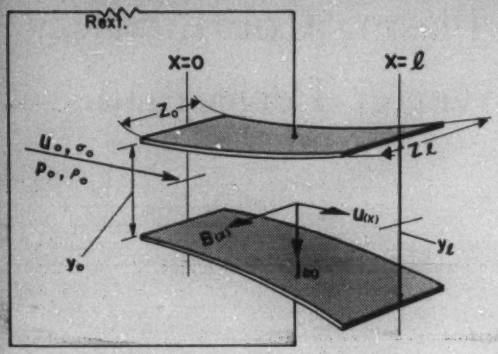


Fig. 1. Schematic diagram of energy converter.

tion and constant magnetic field intensity, both will here be considered as varying functions.) With the given directions for the magnetic field and the flow, an electric field is induced in the y direction, so that a potential difference thereby appears across the electrodes. The electrodes then are the terminals of the converter, and a load resistor connected across them will permit a current to flow.

The flow equations which apply to the plasma are the usual one-dimensional steady-state fluid dynamic equations of motion, with additional terms to account for the effect of the magnetic field on the flow. These equations are the continuity equation

$$\frac{d}{dx}(\rho u y z) = 0 \tag{1}$$

the momentum equation

$$\rho u \frac{du}{dx} + \frac{dp}{dx} + jB = 0 \tag{2}$$

and the energy equation

$$\frac{d}{dx}\left[\rho u y z \left(c_p T + \frac{1}{2}u^2\right)\right] + jBuyz - \frac{j^2 yz}{\sigma} = 0 \tag{3}$$

where ρ is the fluid density, u is the fluid velocity, p is the static pressure, j is the induced current density, c_p is the constant pressure specific heat, T is the static temperature, and σ is the local electrical conductivity of the plasma. In the momentum equation, the term jB is the reactive force per unit volume exerted by the magnetic field on the plasma. In the energy equation, the term $jBuyz$ is the rate at which work is done per unit length of channel by the plasma against the reactive force, and would be the power delivered to the external load in the absence of internal losses. The term j^2yz/σ is the power per unit length of channel dissipated within the plasma due to Joulean heating. For infinite conductivity, this vanishes.

In addition to the fluid dynamic equations, an expression for the current density can be written for an assumed load on the converter. Let the load be such that the terminal voltage is V. Then the current in the slab of plasma of thickness dx, height y, and depth z is

$$jzdx = (uBy - V)\left(\sigma\frac{zdx}{y}\right)$$

where the first factor on the right is the internal voltage drop and the second is the conductance of the slab. Thus

$$j = \sigma\left(uB - \frac{V}{y}\right) \tag{4}$$

One further equation is provided by the equation of state. Since the plasma is assumed to be an ideal gas, we can write

$$p = \rho RT = \frac{\gamma - 1}{\gamma}\rho c_p T \tag{5}$$

where R is the gas constant for the plasma and γ is the specific heat ratio.

Equations 1 through 5 constitute five equations in the five unknown functions ρ, u, p, T, and j. An immediate reduction to two equations in p and u can be made by using equations 4 and 5 and the integral of equation 1 to eliminate ρ, T, and j in equations 2 and 3. We obtain then

$$\frac{du}{dx} + \frac{yz}{m}\frac{dp}{dx} + \frac{B\sigma yz}{m}\left(uB - \frac{V}{y}\right) = 0 \tag{6}$$

and

$$\frac{d}{dx}\left(\frac{\gamma}{\gamma - 1}yzup + \frac{1}{2}mu^2\right) + V\sigma z\left(uB - \frac{V}{y}\right) = 0 \tag{7}$$

where m, the mass flow rate, is the constant of integration of equation 1.

In order to make the parametric studies discussed later, it is convenient to nondimensionalize equations 6 and 7. For this purpose we introduce the following nondimensional quantities:

$$\text{Channel length } \delta = \frac{B_o^2 y_o z_o \sigma_o}{m} l \tag{8}$$

$$\text{Velocity } U = u/u_o$$
$$\text{Static pressure } P = p/\rho_o u_o^2$$
$$\text{Channel height } Y = y/y_o$$
$$\text{Channel depth } Z = z/z_o$$
$$\text{Electrical conductivity } \bar{\sigma} = \sigma/\sigma_o$$
$$\text{Magnetic field strength } \bar{B} = B/B_o$$
$$\text{Mach number } M = u/(\gamma RT)^{1/2}$$
$$\text{Load parameter } K = 1 - \frac{V}{u_o B_o y_o}$$
$$\text{Independent variable } \xi = (\delta/l)\, x$$

The subscript o refers to the channel entrance conditions, and l is the dimensional channel length. Making the required substitutions into equations 6 and 7, we obtain

$$\frac{dU}{d\xi} + YZ\frac{dP}{d\xi} + \overline{B}\sigma YZ\left[\overline{B}U - \frac{1}{Y}(1-K)\right] = 0 \quad (10)$$

and

$$\frac{d}{d\xi}\left(\frac{\gamma}{\gamma-1}YZUP + \frac{1}{2}U^2\right) + (1-K)\overline{\sigma}Z\left[\overline{B}U - \frac{1}{Y}(1-K)\right] = 0 \quad (11)$$

In equations 10 and 11, Y and Z are prescribed functions of ξ, σ is considered a known function of Y, Z, U, and P, and K is the load parameter which can assume prescribed values between zero (open external circuit) and unity (shorted external circuit). The determination of $U(\xi)$ and $P(\xi)$ over the interval $0 \leq \xi \leq \delta$ constitutes the solution to equations 10 and 11.

To obtain an expression for the electrical conductivity, we assume that the entire current is carried by the electrons. Thus

$$\sigma = \frac{j}{E} = \frac{n_e e u_e}{E} \quad (12)$$

where n_e is the number density of electrons, e the electronic charge, u_e the drift velocity of electrons through the gas, and E the electric field intensity. In general, the electron mobility u_e/E is limited by collisions with neutral gas atoms and by long-range Coulomb interactions with other charged particles. The former process predominates in a weakly ionized gas, and the latter in a strongly ionized gas. If $1/\sigma_1$ is the resistivity of the gas due to electron collisions with neutral gas atoms and $1/\sigma_2$ the resistivity due to long-range Coulomb interactions, we assume, then, that for a gas of intermediate ionization, in which both processes are significant, the resistivity is given by the sum of the resistivities due to the two processes as follows:[3]

$$\frac{1}{\sigma} = \frac{1}{\sigma_1} + \frac{1}{\sigma_2} \quad (13)$$

For a weakly ionized gas in which the electric field is not large enough to cause ionizing collisions, the collision encounters between electrons and neutral gas atoms are mostly elastic. In such a gas Chapman's theory[4] for electron mobility gives

$$\frac{u_e}{E} = \frac{2}{3}\sqrt{\frac{2}{\pi}}\frac{e}{Qp}\left(\frac{kT}{m_e}\right)^{1/2} \quad (14)$$

where Q is the electron–gas atom collision cross section, k is Boltzmann's constant, T is the gas temperature, and p is the pressure. (Although Q is a function of temperature, for this study it is taken as a suitable constant for the temperature ranges of interest.)

The number density of electrons as required by equation 12 can be obtained from Saha's equation,[5] assuming that the gas as a whole is electrically neutral and that the electrons are in equilibrium with the gas. We further assume that for temperatures of interest we can ignore all internal states of the gas atoms and their ions except the states of lowest energy. Saha's equation can then be written

$$n_e^2 = p\frac{g_e g_i}{g_a}\left(\frac{2\pi m_e k^{1/3}T^{1/3}}{h^2}\right)^{3/2}\exp(-\phi kT) \quad (15)$$

where $g_e(=2)$ is the multiplicity of the electron, g_i and g_a are the respective multiplicities of the ground states of the ion and neutral atom, h is Planck's constant, and ϕ is the ionization potential.

Substituting into equation 12 for the mobility as given by equation 14, and for the electron particle density as given by equation 15, we have for a weakly ionized gas

$$\sigma_1(p,T) = \frac{(2^9\pi)^{1/4}}{3}\frac{e^2 m_e^{1/4}k^{3/4}}{h^{3/2}}\left(\frac{g_e g_i}{g_a}\right)^{1/2}\frac{1}{Q}\frac{T^{3/4}}{p^{1/2}}\exp(-\phi/2kT) \quad (16)$$

For fully ionized gas, the electrical conductivity as given by Spitzer and Härm[6] is, in MKS (meter-kilogram-second) units

$$\sigma_2 = \frac{2^{13/2}\pi^{1/2}\kappa_o^2\gamma_E k^{3/2}T^{3/2}}{m_e^{1/2}Ze^2\ln(qc^2)} \quad (17)$$

where κ_o is the permittivity of free space, γ_E is a correction factor to account for electron-to-electron encounters, and Ze is the ionic charge;

$$q = \frac{4\pi\kappa_o^{3/4}m_e(kT)^{1/2}}{Z(Z+1)^{1/2}e^3 n_e^{1/2}} \quad (18)$$

and

$$c = \left(\frac{3kT}{m_e}\right)^{1/2} \quad (19)$$

For a singly ionized gas, $Z = 1$ and $\gamma_E = 0.5816$. For a fully ionized gas,

$$n_e = \frac{p}{2kT} \quad (20)$$

Equations 17 through 20 combine to express σ_2 as a function of p and T. The results, together with equation 16, are substituted into equation 13 to provide the conductivity function, which is then nondimensionalized according to equation 9, where σ_o is the conductivity evaluated at the entrance to the channel.

The power output of the converter is given by

$$\hat{P} = V\int_o^l jz\,dx = V\int_o^l \sigma z\left(uB - \frac{V}{y}\right)dx$$

Substituting for the integrand from equation 7, the output power can be expressed in the following convenient form:

$$\hat{P} = h_T(o) - h_T(l)$$

where

$$h_T(x) = \frac{\gamma}{\gamma-1}yzup + \frac{1}{2}mu^2$$

is the stagnation enthalpy flux at x. A measure of the output power is therefore provided by the conversion

effectiveness η_c, which is defined as the ratio of the output power to the stagnation enthalpy flux at the entrance to the channel:

$$\eta_c = \frac{\bar{P}}{h_T(o)} = 1 - \frac{h_T(l)}{h_T(o)} = 1 - \frac{T_T(l)}{T_T(o)} \tag{21}$$

where T_T is the stagnation temperature, c_p being assumed constant. The nondimensional stagnation enthalpy flux is defined by

$$H_T(\xi) = \frac{h_T(x)}{mu_o^2} \tag{22}$$

In terms of nondimensional quantities, this can be written

$$H_T(\xi) = \frac{1}{\gamma - 1}\left[\frac{U(\xi)}{M(\xi)}\right]^2 + \frac{1}{2}\left[U(\xi)\right]^2 \tag{23}$$

A measure of the irreversibility of the flow due to Joulean dissipation within the fluid is given by the isentropic efficiency η_s, which is defined as the ratio of the decrease in the stagnation enthalpy flux in the channel to the decrease in the stagnation enthalpy flux which would result from an isentropic flow process terminating in an exit stagnation pressure equal to that of the actual flow. Thus

$$\eta_s = \frac{h_T(o) - h_T(l)}{h_T(o) - h'_T(l)} = \frac{\eta_c}{1 - \dfrac{h'_T(l)}{h_T(o)}} = \frac{\eta_c}{1 - \dfrac{T'_T(l)}{T_T(o)}}$$

again assuming the constancy of the specific heat. Here $h'_T(l)$ and $T'_T(l)$ are respectively the exit stagnation flux and temperature for the isentropic flow process. We can also write for the isentropic process

$$\frac{T'_T(l)}{T_T(o)} = \left[\frac{p_T(l)}{p_T(o)}\right]^{(\gamma-1)/\gamma}$$

where p_T is the total pressure, and where $p_T(l)$ is the exit total pressure for both the actual flow and the isentropic flow. Thus

$$\eta_s = \frac{\eta_c}{1 - \left[\dfrac{p_T(l)}{p_T(o)}\right]^{(\gamma-1)/\gamma}}$$

To compute η_s, therefore, we must express the total pressure ratio $p_T(l)/p_T(o)$ across the channel in terms of the solutions of equations 10 and 11. To do this, we note that the stagnation to static pressure and temperature are given respectively by

$$\frac{p_T}{p} = \left[1 + \frac{1}{2}(\gamma - 1)\, M^2\right]^{\gamma/(\gamma-1)}$$

and

$$\frac{T_T}{T} = 1 + \frac{1}{2}(\gamma - 1)\, M^2 \tag{24}$$

so that

$$\frac{p_T(l)/p_T(o)}{p(l)/p(o)} = \left[\frac{T_T(l)/T_T(o)}{T(l)/T(o)}\right]^{\gamma/(\gamma-1)}$$

or

$$\left[\frac{p_T(l)}{p_T(o)}\right]^{(\gamma-1)/\gamma} = \frac{p_r}{T_r} \quad \text{and} \quad \frac{T_T(l)}{T_T(o)} = \frac{p_r}{T_r}^{(\gamma-1)/\gamma} \quad (1-\eta_c)$$

where p_r and T_r are the respective static pressure and temperature ratios across the channel and are given by

$$p_r = \gamma M_o^2 P(\delta)$$

and

$$T_r = \gamma M_o^2 Y(\delta) Z(\delta) U(\delta) P(\delta)$$

Thus the isentropic efficiency can be written

$$\eta_s = \frac{\eta_c}{1 - \dfrac{p_r}{T_r}^{(\gamma-1)/\gamma} (1-\eta_c)}$$

An additional parameter of interest is the generated power density $\bar{p}$ defined as the ratio of the power output to the volume v of the channel:

$$\bar{p} = \frac{h_T(o)\eta_c}{v} \tag{25}$$

From equations 22 and 23, it is seen that the entrance enthalpy flux can be written

$$h_T(o) = mu_o^2\left[\frac{1}{(\gamma-1)M_o^2} + \frac{1}{2}\right] \tag{26}$$

The initial velocity may be expressed as

$$u_o = (\gamma R T_o)^{1/2} M_o \tag{27}$$

and by equation 8, the mass flow ratio may be given by

$$m = \frac{B_o^2 y_o z_o \sigma_o d}{\delta} \tag{28}$$

For the volume of the channel, we have

$$v = \int^l yz\, dx = \frac{y_o z_o d}{\delta}\, \bar{v} \tag{29}$$

where we have defined a nondimensional volume by

$$\bar{v} = \int_o^\delta YZ d\xi \tag{30}$$

Substituting the expressions given by equations 26 through 29 into equation 25 and using equation 24, we obtain

$$\bar{p} = \frac{\gamma}{\gamma - 1} B_o^2 \sigma_o R T_T(o) \frac{\eta_c}{\bar{v}} \tag{31}$$

Except for channel shape, magnetic field distribution and gas data (γ, R, g_i, g_a, ϕ, and Q), the input

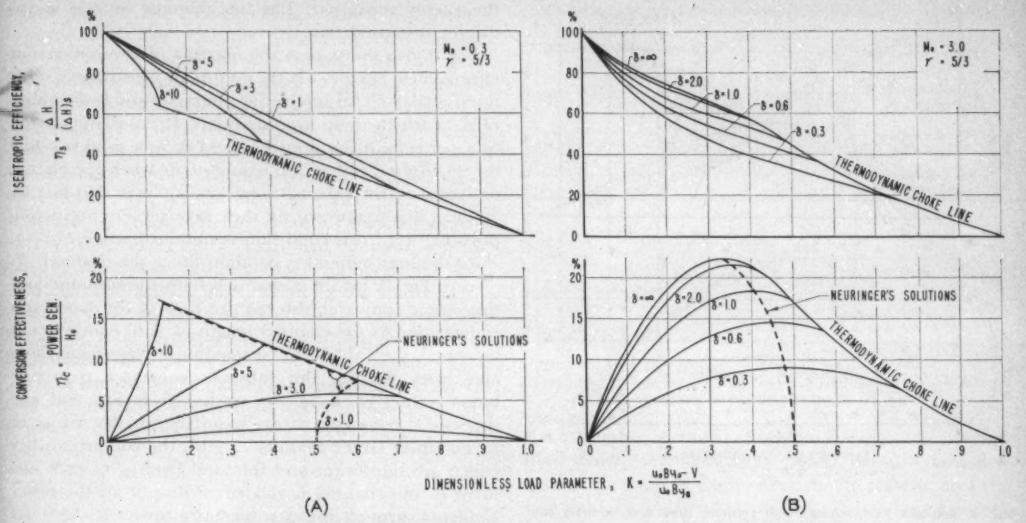


Fig. 2. (A) Subsonic and (B) supersonic performance, with constant area and constant conductivity.

parameters needed to compute η_c and η_s are M_o, δ, K, T_o[or $T_T(o)$], and p_o[or $p_T(o)$], the temperature and pressure being needed only in the conductivity function. The computation of $\overline{p}$ also requires B_o.

DISCUSSION AND RESULTS

THE NONDIMENSIONAL EQUATIONS 10 and 11 were solved numerically, using the IBM *704* digital computer. The performance of the MHD energy converter was calculated for constant channel cross-sectional area ($Y = 1$ and $Z = 1$) and for a constant magnetic field ($\overline{B} = 1$). The specific heat ratio γ was taken as 5/3, representing either a monatomic gas or a fully ionized plasma.

The performance was computed for a constant area energy converter; first with an assumed constant plasma conductivity ($\sigma = 1$), then for a specified working fluid with the plasma conductivity, given by equations 9, 13, 16, and 17, as a function of the local thermodynamic properties of the plasma. The performance was obtained for a variety of subsonic and supersonic entrance Mach numbers M_o and for a variety of nondimensional channel lengths δ, the load parameter K ranging from open circuit ($K = 0$) to short circuit ($K = 1$).

Fig. 2 presents the performance of the constant area energy converter for an assumed constant plasma conductivity.

The performance of a subsonic energy converter is shown in Fig. 2 (A) for an entrance Mach number of 0.3. The isentropic efficiency η_s and the conversion effectiveness η_c are plotted as functions of the load parameter K for a range of channel lengths δ. For small values of δ, the conversion effectiveness increases and the isentropic efficiency decreases as K is increased from zero. At approximately $K = 1/2$, the conversion effectiveness is a maximum, and further increases in K cause η_c to decrease until at $K=1$ the energy converted becomes zero. The isentropic efficiency continually decreases with increasing K until it also goes to zero at $K = 1$. When $K = 1$, the converter is short circuited and all the gas dynamic energy removed from the plasma is returned in the form of Joulean dissipation. For larger values of δ, K cannot be increased beyond a certain limiting value. This limit is imposed by the flow becoming sonic at the exit of the channel. When this occurs the flow is choked. The locus of this condition is indicated by the line labeled "thermodynamic choke line." Thus, it is seen that for shorter channels, the maximum energy conversion occurs when the loading is chosen in a manner which best matches the energy output to the Joulean dissipation; for longer channels, the maximum energy conversion is dictated by the thermodynamic choking of the flow.

At a fixed value of loading, increasing the length of the converter causes an increase in η_c and a decrease in η_s. It also increases the exit flow Mach number until the choke condition is reached. For the subsonic converter, the flow velocity increases along the channel length. This produces a larger induced emf and thus requires larger internal voltage drops to match the terminal voltage specified by K. Each subsequent increment in length added to the channel converts additional energy, but does so with poorer local efficiency.

The performance for the supersonic converter is shown in Fig. 2(B) for an entrance Mach number of 3.0. The thermodynamic choke line again denotes the operating conditions where the exit flow Mach number

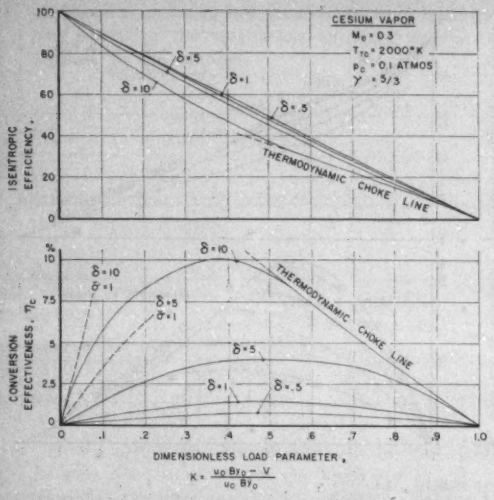


Fig. 3. Subsonic performance, with constant area and variable conductivity.

is unity. As opposed to the subsonic converter, at a fixed value of loading, both the conversion effectiveness and the isentropic efficiency of the supersonic converter increase as the length of the channel is increased. For this case, the flow velocity decreases along the length of the channel, causing a reduction in the induced emf. This requires, therefore, a smaller internal voltage drop in order to match the specified terminal voltage. Thus, subsequent increments of length added to the channel convert energy with a local efficiency that is better than the average for the channel. For lightly loaded operations, i.e., small values of K, the drop in velocity causes induced emf to approach the terminal voltage asymptotically. When this occurs, further lengthening of the channel produces no change in the flow conditions or the energy converted. The line denoted by $\delta = \infty$ indicates this condition.

Fig. 2 also shows that the maxima of the conversion effectiveness agree with the results of Neuringer's optimum analysis.[1] An interesting characteristic is the value of K at which these maxima occur. If the plasma acted as a perfectly incompressible fluid or as a solid conductor, maximum conversion would occur when the energy delivered to the external load was equal to that lost by Joulean dissipation within the converter. For an incompressible fluid this condition is obtained when $K = \frac{1}{2}$, since the induced emf is constant down the channel. As seen in Fig. 2, for short channels both the subsonic and supersonic converter also require $K \sim \frac{1}{2}$ for maximum conversion. As the channel length of both converters is increased, the value of K at maximum conversion deviates from $K = \frac{1}{2}$, the subsonic converter requiring larger values of K in the unchoked region and the supersonic converter always requiring smaller values of K. For these larger channel lengths, the compressibility effects are significant and the local loading of each element of the channel is related to that of all the other elements through the gas dynamics involved. As a result, the condition for maximum conversion is no longer simply that required by a solid or incompressible conductor.

In order to study the effect of a variable conductivity plasma upon the performance of the MHD energy converter, a choice must be made of the working fluid and its initial conditions. For this investigation cesium vapor was chosen as the working fluid, the choice being dictated by its low value of ionization potential, $\phi = 3.87$ volts, which will provide reasonable values of plasma conductivity for temperatures in the thermal range. The performance was computed for two values of entrance stagnation temperature, T_{To}. The lower value, $T_{To} = 2{,}000$ K, represents the lowest usable plasma temperature at which present day materials can conceivably operate. The higher value of 5,000 K has been included to indicate the increased performance capability that could be obtained, without regard for the materials problem. All the performance computations reported here for variable plasma conductivity have been made for an entrance static pressure p_o of 0.1 atmosphere. This represents the lowest value for the present choice of working fluid and temperatures that will not violate the assumption of a scalar plasma conductivity.[7]

The conductivity function requires the collision cross section of electrons with atoms as a function of temperature. Because good data were not available in the required temperature range, a value of 3.25×10^{-18} square meters was chosen[8] for cesium, and no dependence upon temperature was included.

The performance of the variable conductivity converter for a subsonic entrance. Mach number of 0.3 is shown in Fig. 3 for the 2,000 K entrance stagnation temperature. The dashed performance lines for the larger values of δ have been reproduced from Fig. 2(A) for comparison, and show the performance for constant conductivity. In the subsonic converter, the thermody-

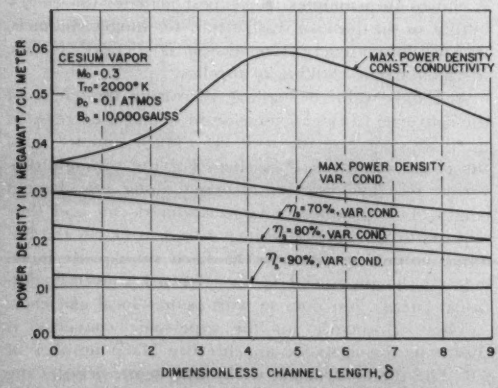

CESIUM VAPOR
$M_o = 0.3$
$T_{To} = 2000°K$
$p_o = 0.1$ ATMOS
$B_o = 10{,}000$ GAUSS
MAX. POWER DENSITY CONST. CONDUCTIVITY
MAX. POWER DENSITY VAR. COND.
$\eta_s = 70\%$, VAR. COND.
$\eta_s = 80\%$, VAR. COND.
$\eta_s = 90\%$, VAR. COND.
POWER DENSITY IN MEGAWATT/CU METER
DIMENSIONLESS CHANNEL LENGTH, δ

Fig. 4. Power density as a function of channel length.

namic state of the plasma changes down the channel towards sonic flow; i.e., the plasma velocity increases and the plasma temperature decreases. This causes the local value of plasma conductivity to decrease along the length of the channel. The indicated loss in performance reflects this decreasing conductivity. The resulting thermodynamic choke line is identical to that obtained for constant plasma conductivity, as can be shown analytically. The values of K at which maximum η_c occur are lower for variable σ than for the computation of Fig. 2(A), in which σ is assumed constant. For the case of supersonic entrance Mach numbers, the local value of conductivity increases along the length of the channel and results in an increase in converter performance. The consequences of this characteristic will be indicated in some of the subsequent results.

For a constant area channel the nondimensional volume, as given by equation 30, reduces to $v = \delta$. The density $\bar{p}$ given by equation 31 then becomes

$$\bar{p} = \frac{\gamma}{\gamma - 1} B_o^2 \sigma_o R T_{To} \frac{\eta_c}{\delta} \tag{32}$$

The constant magnetic field strength B_o was chosen to be 10,000 gausses for all of the computations of power density. The conductivity of the plasma at the entrance to the channel σ_o is based upon the entrance static pressure and temperature. The static pressure for all of this work was chosen to be 0.1 atmosphere; the static temperature was determined by equation 24 from the stagnation temperature T_{To} and Mach number M_o. Thus, for a specified working fluid, entrance Mach number M_o and stagnation temperature T_{To}, the power density $\bar{p}$ becomes a function of the ratio of η_c to δ.

Fig. 4 shows the dependence of this function upon the choice of δ, for the indicated initial conditions. The curves labled "maximum power" are obtained by choosing the maximum value of η_c for each δ, from curves similar to those presented in Figs. 2 (A) and 3. For the case of constant conductivity at the lower values of δ the maximum value of η_c occurs as an extremum, and at the higher values of δ it occurs as the result of the Mach number limit. For variable conductivity, the performance is substantially reduced, and at all values of δ calculated, η_c occurs as an extremum. Also included in Fig. 4 are power densities for various constant values of isentropic efficiency η_s. These curves are included to show how the power density would be decreased from its maximum if high isentropic efficiency were an important design consideration.

For temperatures of the order of 2,000 K, the conductivity of a cesium plasma will vary predominantly as an exponential function of temperature as indicated by equation 16. The entrance static temperature decreases for increasing values of entrance Mach numbers and fixed values of T_{To}. Although this results in a large reduction in σ_o, the maximum power density for small subsonic Mach numbers increases with Mach number, as shown in Fig. 5 for $T_{To} = 2{,}000$ K. As seen from equation 32, this is possible only because the ratio of η_c to δ increases faster than σ_o decreases. As the entrance

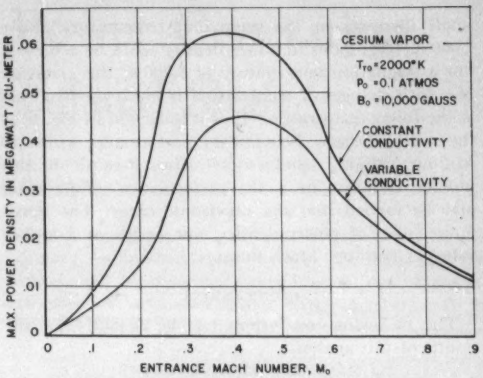


Fig. 5. Maximum power density for $T_{To} = 2{,}000$ K.

Mach number is further increased, a point is reached after which the maximum power density decreases, since at the high Mach number the decrease in σ_o is the dominant factor in equation 32. The value of power density for supersonic entrance Mach numbers has not been calculated for $T_{To} = 2{,}000$ K due to the extremely low values of plasma conductivity. The sensitive nature of the conductivity function at temperatures in this range causes an appreciable variation in the power density that can be achieved when the plasma conductivity is allowed to vary in a realistic manner as opposed to holding it constant. The performance shown in Fig. 5 indicates an overestimation of about 40% in power density if the conductivity is assumed to be constant.

The performance shown in Fig. 6 is for an entrance stagnation temperature of 5,000 K. The large increase in the level of power density is mainly due to the exponential increase in the level of conductivity, although the increased stagnation temperature itself causes an increase by a factor of 2.5. This would indicate that for

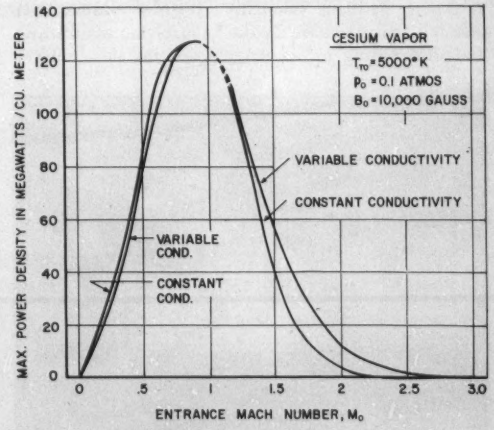


Fig. 6. Maximum power density for $T_{To} = 5{,}000$ K.

small increases in the stagnation temperature above 2,000 K, large gains in power density could be achieved. For a stagnation temperature of 5,000 K, the variation of σ with changes in temperature is much smaller than at the lower temperature. This is indicated in Fig. 6 by the small difference between the performance with and without variable conductivity. Also, because of this smaller variation in σ, the performance computation may be carried into the supersonic range. The maximum value of power density now occurs at a higher value of entrance Mach number.

CONCLUSIONS

The following conclusions can be drawn from the results of this analysis:

1. At sufficiently high temperatures ($\sim$ 5,000 K), the constant conductivity approximation does not introduce serious error in the performance computation; however, at lower temperatures ($\sim$ 2,000 K), the approximation significantly overestimates the performance and, therefore, cannot be ignored.

2. The required entrance flow Mach number for maximum power density increases as the entrance stagnation temperature is increased. For the temperature range of immediate interest (2,000 to 5,000 K), the required entrance Mach number is always subsonic. In the construction of an actual MHD energy converter, the subsonic Mach number requirement permits more flexibility in the design and lends more validity to the approximations made in the analysis than would be true for a supersonic energy converter.

3. The attainable power density increases sharply with increases in entrance stagnation temperature. Since the maximum temperature that an MHD energy converter can operate at is limited by the capabilities of the materials involved, the reward of large increases in performance for small increases in operating temperatures provides a strong incentive for sophistication in design and for the accomplishment of even small increases in materials capability.

REFERENCES

1. Optimum Power Generation Using a Plasma As A Working Fluid, J. L. Neuringer. *Proceedings*, Third Biennial Gas Dynamics Symposium, Northwestern University Press, Evanston, Ill., 1960, pp. 153-67.

2. The Performance Characteristics of a Constant Area MHD Energy Converter with Assumed Constant Plasma Conductivity, C. L. Eisen, W. B. Coe. *Report no. PPL-TN-60-7*, Republic Aviation Corporation, Farmingdale, N. Y., Mar. 1960.

3. Electrical Conductivity of Highly Ionized Argon Produced by Shock Waves, S. Lin, E. L. Resler, A. Kantrowitz. *Journal of Applied Physics*, New York, N. Y., vol. 26, 1955, pp. 95-109.

4. Kinetic Theory of Gases (book), E. H. Kennard. McGraw-Hill Book Company, Inc., New York, N. Y., 1938, pp. 470-73.

5. *Ibid.*, pp. 243-45.

6. Transport Phenomena in A Completely Ionized Gas, L. Spitzer, R. Härm. *Physical Review*, New York, N. Y., vol. 89, 1953, pp. 977-81.

7. The Mathematical Theory of Non-Uniform Gases (book), S. Chapman, T. G. Cowling. Cambridge University Press, Cambridge, England, 1952, p. 328.

8. Basic Data of Plasma Physics (book), S. C. Brown. John Wiley & Sons, Inc., New York, N. Y. 1959, p. 6.

Missile Bomber Electric Systems

A portion of the complete a-c and d-c mock-ups for the B-52G and the new B-52H missile bombers is shown here in the Electrical and Electronic Design Laboratory at Boeing Airplane Company's Wichita (Kans.) Division. The mock-ups are capable of receiving, controlling, and distributing to simulated loads the power developed by the alternators of the electric systems of the U. S. Air Force Strategic Air Command bombers.

In addition, the area contains a complete aircraft d-c power system including load-simulation capabilities. Present work is concentrated on evaluation of the 120-kva system for the B-52H. The oscillograph (*left foreground*) is used in monitoring the new 120-kva system, which has 470 switches, 915 circuit breakers, 320 relays, and about 68½ miles of wiring, some of which can be seen in the panels along the extreme left edge of the photograph. The B-52H can generate a maximum of 480 kva, as compared with 160 kva on the B-52G.

Both the B-52G and the B-52H electric systems are being evaluated at Boeing-Wichita under extreme, adverse conditions to simulate operating conditions which might be encountered in actual flight.

Power for the mock-ups is generated from an area immediately adjacent in the form of 115/208-volt 3-phase 400-cycle loading facilities. These can supply continuously variable loads up to 480 kw at 0.999 power factor and 400 kvar at 0.05 power factor or any combination thereof, with a resulting maximum current load to 562 kva at 0.75 power factor.

Precise-Frequency Power Generation from an Unregulated Shaft

K. M. CHIRGWIN
ASSOCIATE MEMBER AIEE

L. J. STRATTON
ASSOCIATE MEMBER AIEE

J. R. TOTH

The system described generates precise-frequency power from an unregulated shaft through use of a high-frequency variable-speed brushless generator, a semiconductor frequency changer, an output filter, and a voltage and frequency regulator.

GENERATOR SYSTEMS capable of generating power at a very precisely controlled frequency despite wide variations in the speed of the prime mover have been described previously.[1] These systems were designed specifically to meet aircraft main generator requirements. The best system for these requirements was found to be a synchronous flux system using a wound-rotor induction machine as the main generator with a combination of semiconductor frequency changer and synchronous machine handling the slip or make-up power.

Also discussed in this paper[1] was a so-called full-rated system in which all the power is generated at a frequency which varies with the speed of the shaft, and is then changed to the precise-frequency power in a semiconductor frequency changer. It is the purpose of this article to discuss this full-rated system, and to examine its advantages and the situations in which it can be applied to best advantage.

An obvious way of obtaining precise-frequency power from an unregulated shaft is to rectify the output of a variable-frequency generator driven by the shaft and then to convert the resulting d-c power to precisely controlled frequency power by a static inverter. The advantage of this method is that the frequency of the output power is dependent only on the frequency of the reference signal used to control the static inverter, and is not affected by changes in load on the system or speed of the shaft.

The rectifier and static inverter part of this scheme can be classified as a "d-c link" frequency changer,[2] since the a-c power is changed to d-c, and then statically inverted to the desired a-c frequency. Such a frequency changer has the disadvantage that it cannot feed a lagging reactive load, because the rectifier portion permits power flow in only one direction. A further disadvantage is that this d-c link frequency changer is a dual energy-conversion device.

A system employing a single energy-conversion frequency changer which converts directly from one frequency to another, and therefore has only half the losses, will be described. Furthermore, this frequency changer permits power flow in either direction and can handle loads of any power factor.

Essentially full text of paper 60-989, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee. Scheduled for publication in AIEE *Applications and Industry*, Jan. 1961.

K. M. Chirgwin, L. J. Stratton, and J. R. Toth are with Jack & Heintz, Inc., Cleveland, Ohio.

SYSTEM BLOCK DIAGRAM

A BLOCK DIAGRAM of the system is shown in Fig. 1. It consists of a synchronous generator driven by an unregulated shaft which feeds variable-frequency a-c power to a semiconductor frequency changer. The output power of the frequency changer is precisely controlled frequency. This output is then filtered in order to meet military specifications on waveshape. The frequency of the output power is determined by a signal from a frequency reference which is part of the voltage and frequency regulator. The voltage regulator senses the output voltage and supplies d-c field excitation to the synchronous generator.

FREQUENCY CHANGER

THE POWER CIRCUIT of the frequency changer[3] is shown in Fig. 2. The power supply to the frequency changer is the variable-frequency synchronous generator driven by the unregulated shaft. The frequency changer, as shown in Fig. 2, consists of 18 silicon p-n-p-n switches (silicon controlled rectifier, trinister, etc.). Fig. 3 shows two typical p-n-p-n switches. This component can be rendered conducting or switched on by means of a small pulse of current applied to the gate. It ceases conduction or is switched off when the anode-to-cathode current is forced to zero by circuit conditions. Therefore, the p-n-p-n switch is the solid-state equivalent of a thyratron.

The function of the frequency changer is to convert

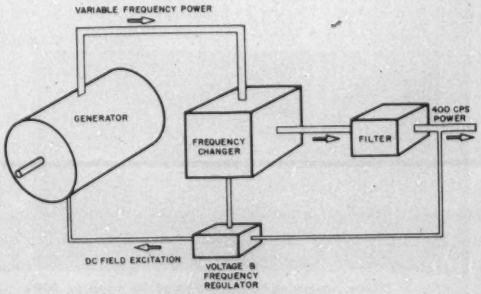


Fig. 1. System block diagram.

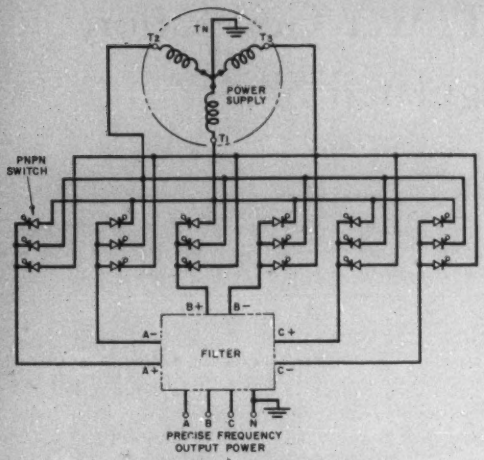


Fig. 2. Frequency-changer power circuit.

higher input frequency alternating current or voltage into a lower output frequency alternating current or voltage.

In essence, the frequency changer is a number of switches which are opened and closed at such instants that the output frequency wave is fabricated out of small pieces of a number of input frequency waves. This process of opening and closing the switches produces a jagged output frequency wave which is smoothed by the filter. Fig. 4 is an illustration of this fabrication process.

The frequency changer illustrated in Fig. 2 consists of six groups of 3-phase half-wave circuits. One half of these groups are called "positive groups" ($A+$, $B+$, $C+$) and the other half, "negative groups" ($A-$, $B-$, $C-$). The function of the positive groups is to carry current during the positive half cycle of the output frequency wave, and the negative groups carry the current during the negative half cycle of the output frequency wave. The output frequency is determined by the length of time the positive groups and the negative groups are each allowed to carry current.

In order to understand the fabrication process, consider one of the positive groups in Fig. 2. Assume, first of all, that the firing of these three rectifiers is delayed to such an extent that the average output voltage is zero.

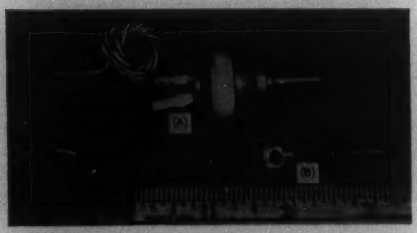


Fig. 3. Silicon p-n-p-n switches: (A) Rated 50 amperes, 300 volts maximum; (B) Rated 16 amperes, 400 volts maximum.

This will represent the zero point on the output voltage wave. Next assume the delay in the firing of the rectifiers is progressively decreased so that the average voltage output of the group is progressively increased to a maximum value. If the delay is decreased in an appropriate manner, the increase in the output voltage can be sinusoidal. Having reached the maximum of the output voltage wave, the delay in the firing of the rectifiers is progressively increased until the voltage output is reduced to zero once again. At this point, if the power factor is unity, the negative group of rectifiers in the same output phase takes over and fabricates the negative half cycle of the output voltage wave.

Thus, all that is necessary in order to fabricate a precise frequency output wave is to control the delay in the firing of the rectifiers in an appropriate manner, to arrange to switch from the positive group to the negative group at appropriate instants, and to filter the output wave. Fig. 4 illustrates that the instant that is appropriate for switching from the positive to the negative group is not necessarily the instant of zero voltage output, but rather the instant of zero current in the output circuit. If the switching from positive to negative groups always occurs at the current zero, it is possible to transmit real or reactive power in either direction through the frequency changer.

From Fig. 4 it is apparent that a number of high-frequency waves should be used in fabricating a low-frequency wave in order to get reasonable output waveshapes. Also, to avoid power pulsations, the ratio of the high to the low frequency should be approximately 2 to 1 or greater. Fig. 5 shows an oscillogram of the fabricated output voltage and the current resulting from a minimum amount of filtering when the frequency ratio is about 10 to 1.

The foregoing description assumes conversion from higher frequency to lower frequency. However, it has been shown that power can flow from the lower-frequency side to the higher-frequency side of the frequency changer. Therefore, the power supply to the frequency changer can be at a lower frequency than the output.[4] Under these conditions, the leading reactive kva required to commutate the current between rectifiers must be provided on the higher-frequency side. Because of this requirement, it is advantageous to have the power supply to the frequency changer at the higher frequency. Furthermore, a high-frequency power supply permits use of a high-speed generator, which means a reduced generator weight. Therefore, frequency changers where power flow is from the lower-frequency side to higher-frequency side are not included in this article.

Just as with a thyratron, there is an upper frequency limit set by the deionization time of the tube; so also with a p-n-p-n switch, there is an upper frequency limit set by its recovery time.[5] As this frequency limit is approached, satisfactory commutation requires that both the frequency changer and the generator be derated by an amount shown by Fig. 6.

Therefore, there are limits on the input frequency

to the frequency changer, the lower limit being approximately twice the output frequency and the upper limit being determined by the utilization and the recovery time (Fig. 6). The frequency at which the generator operates must fall between these limits for the whole speed range of the unregulated shaft. When the output frequency of the system is 400 cps (cycles per second), these frequency limits are wide enough not to present any problem. When the output frequency is 1,600 cps, there may be some weight penalty due to poor utilization if the speed range of the shaft is wide. When the output frequency is 3,200 cps, it will be necessary to use p-n-p-n switches having the shorter recovery time shown at the top of Fig. 6.

WAVE SHAPING

FIGS. 4 AND 5 indicate that the output wave fabricated by the frequency changer has appreciable ripple. The function of the filter in the block diagram of Fig. 1 is to suppress this ripple and give output current and voltage waveshapes meeting military specifications. The size and weight of this filter can be reduced by increasing the frequency and/or decreasing the amplitude of the ripple.

For the circuit of Fig. 2, the ripple frequency is three times the input frequency since this frequency changer circuit is based on a 3-phase half-wave rectifier circuit. Many other basic rectifier circuits could be used to make up a frequency changer which will give increased ripple frequency and decreased ripple amplitude. However, in order to minimize the size and weight of both the generator and frequency changer, it is necessary to use basic rectifier circuits which give 120-degree current conduction in the rectifiers. Because of the increase in the number of p-n-p-n switches and their controls, and the number of interphase transformers required, there is a limit to this method of reducing the filter size.

GENERATOR

AS HAS BEEN ALREADY INDICATED, one of the major advantages of this system is that the generator frequency should be high and, therefore, the generator may be run at very high speeds to minimize its size and weight.[7] In order to make the generator reliable at these high speeds, it is advisable to eliminate the slip rings and brushes. Fig. 7 is an exploded view of a brushless Secsyn (stationary exciter coil synchronous) generator.[8]

The brushless Secsyn generator consists of two stationary field coils which establish a magnetic field that induces voltage in a conventional stator winding by normal generator action.

A more thorough understanding of the construction and operating principles will be aided by a careful study of Figs. 7 and 8. The essential components of the machine are shown in the exploded view of Fig. 7, while the relationship of these components and the flux paths are shown in the cutaway view of Fig. 8.

It should be noted that the rotor consists of a solid magnetic tube with hexagonal pole segments which are magnetically isolated from the remainder of the tube

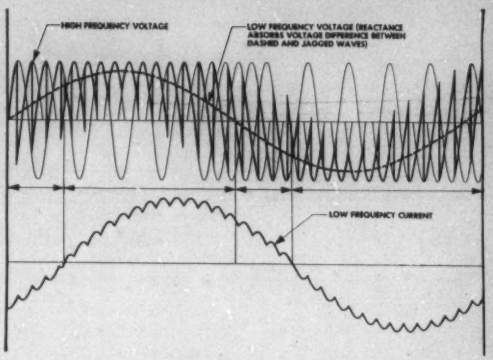

HIGH FREQUENCY VOLTAGE
LOW FREQUENCY VOLTAGE (REACTANCE ABSORBS VOLTAGE DIFFERENCE BETWEEN DASHED AND JAGGED WAVES)
LOW FREQUENCY CURRENT

Fig. 4. Output wave fabrication. Unfiltered voltage and current of 3-phase half-wave frequency changer with 0.7 power factor load.

by a nonmagnetic damper cage. Flux is established in the rotor shaft by two stationary bucking field coils. The flux enters magnetically conductive spokes under each hexagonal pole segment. Therefore, each hexagonal pole segment in the tube surface is a source of flux which crosses the main air gap into the stator, and thereby constitutes a north pole. The flux cuts the armature conductors in the conventional laminated stator, then leaves the stator, again crosses the main air gap, and returns to the surfaces of the tube that exist between the hexagonal pole segments. These surfaces of the tube constitute south poles of the rotor. The flux then progresses axially to the edges of the tube, crosses additional air gaps to the stationary field yokes which surround the field coils, and finally crosses other additional air gaps from the stationary field yokes to the rotating shaft, thus completing the magnetic circuit.

Figs. 7 and 8 illustrate typical 4-pole construction. In a 4-pole machine there are two hexagonal pole segments (north poles, say) and two in-between tube surfaces (south poles) whose active area under the stator iron is equal to the area of the hexagonal segments. The

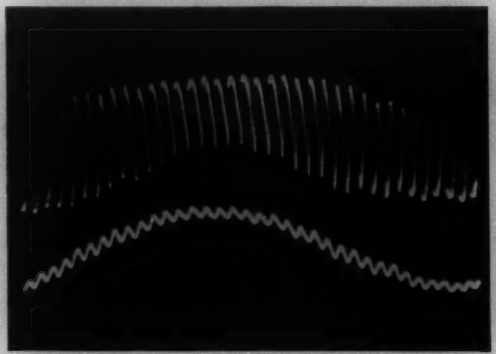
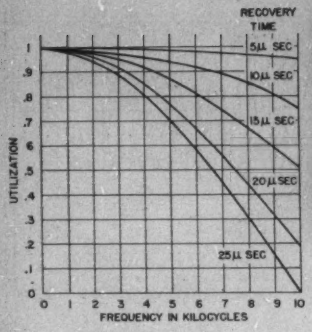


Fig. 5. Oscillogram of output voltage and current for 10-to-1 frequency ratio.



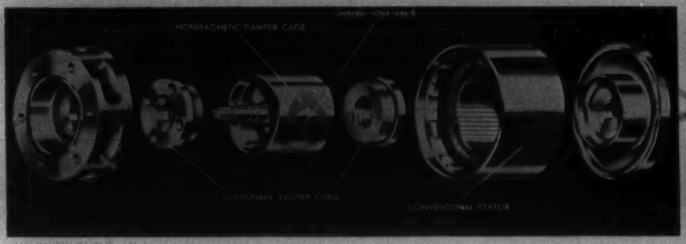


Fig. 6. (left). Utilization curves for frequency changer and generator. Fig. 7. (above). Exploded view of brushless Secsyn generator.

shape of the south poles is complementary to that of the hexagonal north poles so that the flux pattern over north and south poles is symmetrical.

The Secsyn generator, in addition to being brushless, has a rotor construction which is suitable for operation at very high speeds. Because of the absence of rotating windings and because of the tubular steel construction, rotor peripheral velocities as high as 45,000 feet per minute are possible. High peripheral velocities permit building quite large ratings for operation at very high rotational speeds. Fig. 9 shows the maximum rating of Secsyn machines which can be built with a given peripheral velocity and speed of rotation. These curves apply to the operation of the generator at maximum speed. If the output of the system is to be maintained constant over the whole of the speed range, then the size and weight of the generator is determined by the minimum speed of operation.

VOLTAGE AND FREQUENCY REGULATOR

THE OUTPUT VOLTAGE of the system can be regulated in the normal way by controlling the excitation of the generator. The accuracy and speed of response of such a voltage-regulation system will be the same as those of conventional systems. With the type of frequency changer described, there is the possibility of regulating the system voltage in the frequency changer itself. This method of voltage regulation offers the same accuracy but faster response. Either or both methods of voltage regulation may be used, depending upon the requirements of the application.

The output frequency of the system is not affected by shaft speed or load on the system, but is determined by the frequency of the reference signal. The steady-state accuracy of the system frequency is the same as that of the reference. An accuracy of 1% can be achieved with a tuned oscillator, 0.1% with a tuning fork, and 0.001% with a crystal oscillator.

The frequency portion of the control can be operated as an open-loop type regulator. With such a regulator, the only frequency transient that exists in the frequency changer is a certain amount of wave distortion which occurs when the input speed changes rapidly. Certain designs of filter lead to a load-dependent phase shift between input and output voltages. With this type of filter, a small additional frequency transient will be present at the output terminals, when the load changes rapidly. It should be pointed out, however, that these frequency transients are so much smaller than those encountered in conventional systems that new definitions of frequency and frequency transient are needed before discussion can be meaningful.

SYSTEM REACTIVE POWER RELATIONS

IT HAS BEEN SHOWN that this single conversion frequency changer can handle power flow in either direction. This means that energy which has been stored in the load, either inductively or capacitively, during one part of the low-frequency cycle, can be returned, through the frequency changer, to the high-frequency power supply during some other part of the low-frequency cycle.

Since real power is conserved, the real power supplied by the generator must be equal to the real power consumed in the load plus the real power losses in the frequency changer and filter. Unfortunately, the same simple relationship does not apply to reactive power, since reactive power is not necessarily conserved in a system in which there is a frequency change.

The frequency changer of Fig. 2 is built up from a number of 3-phase half-wave phase-delayed rectifier circuits. A typical model is shown in Fig. 10. Rectifier technology[6] shows that the a-c system supplying a phase-delayed rectifier circuit always operates at a lagging power factor. This a-c system power factor is usually defined as the product of two other factors, the distortion factor and the displacement factor. The distortion factor is a measure of the amount of harmonic currents flowing in the system, and the displacement factor is a measure of the amount of the phase displacement between the system voltage (assumed sinusoidal) and the fundamental of the current.

When the rectifier circuits are supplied directly by an a-c generator, the harmonic currents flowing increase the copper losses in the armature and damper windings, but do not have an appreciable effect on the generator armature reaction. With a generator of normal design, it is possible to proportion the armature and damper

windings to take care of the increased losses associated with usually encountered values of the distortion factor without much difficulty. The displacement between the voltage and the current fundamental has the same direct relationship to the demagnetizing effect of armature reaction as does the power factor of a generator carrying sinusoidal currents. Because of this, the displacement factor is important in determining the size and weight of the generator.

In a phase-delayed rectifier, the magnitude of the displacement factor is determined by the amount of phase delay and by the amount of current overlap between phases. With a frequency changer, the power factor of the low-frequency load must be added to this list. Each of these factors will be considered separately.

As would be expected, current overlap between phases reduces the displacement factor. The amount of current overlap depends on the leakage reactance of the generator and of the feeders connecting the generator to the frequency changer. It is important, therefore, to minimize these two reactances, particularly when the generator frequency is high.

When voltage regulation is accomplished, either partially or entirely within the frequency changer, there will be a phase delay caused by the voltage regulator. The greater the amount of voltage reduction, the greater is the phase delay and the greater is the generator reactive power requirement. Fortunately, this does not usually represent a severe penalty on the whole system, since the determining condition is the maximum system overload, and at this overload the voltage reduction called for by the regulator will be zero or only a small value. Thus, the extra generator reactive power required is zero or small.

In a phase-delayed rectifier, because the output is direct current, there is never any reactive power absorbed by the load. With a frequency changer, the load may either absorb or deliver reactive power. It is shown in the appendix that when the load on the frequency changer has zero reactive power (pure resistive load), there is an average phase delay—as a result of shaping the output to a sine wave—which results in a displacement factor of 0.843. When the frequency changer load absorbs reactive power (lagging load), the phase delay is increased and the displacement factor is less than 0.843, as shown in Fig. 20 of reference 9.

When the load delivers reactive power to the frequency changer (leading load), a rather surprising thing happens. Instead of reducing the phase delay and even producing a phase advance, the leading load increases the phase delay and reduces the displacement factor by just the same amount as a lagging load having the same power factor. This means that those filter designs which represent a leading or capacitive load on the frequency changer do not reduce the generator reactive power requirements but actually increase these requirements, and so represent a penalty to the system.

FREQUENCY CHANGER OUTPUT WAVESHAPE

THE MODE OF OPERATION of the frequency changer that has been used in the preceding discussion results in a voltage output wave, which is a sine wave of the desired frequency plus some unwanted higher-frequency ripple. The purpose of the filter is to eliminate this unwanted higher-frequency ripple.

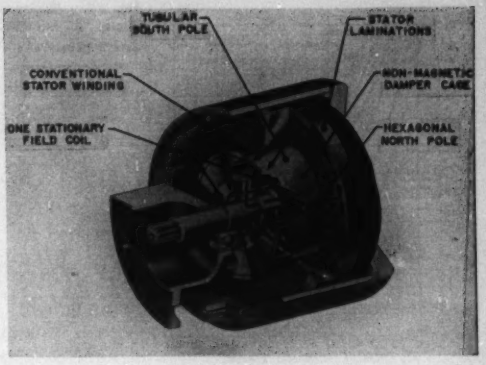


Fig. 8. Cutaway view of brushless Secsyn generator showing flux paths.

It is a comparatively simple matter to program this same frequency changer to produce almost any kind of output waveshape. In applications where a nonsinusoidal waveshape is required, this should be done.

In applications requiring sine wave output, it is possible to produce, for example, an approximately rectangular wave and to filter this to a sine wave. Operating the frequency changer with a rectangular wave output has the advantage that there is only a very small average phase delay caused by wave shaping, and this reduces the generator reactive power requirements by almost 54% of the real power output. On the other hand, the filter now has to eliminate harmonics of the output frequency and, in most applications, this results in a considerable increase in size and weight of the filter. In the majority of applications, a lighter system results from a sine wave frequency changer, a small filter, and a generator capable of the extra reactive power required for wave shaping.

SUMMARY OF SYSTEM CHARACTERISTICS

THE COMPONENTS of the system have each been described in the foregoing sections. When properly combined, these components lead to a system whose more important characteristics follow:

1. Precise frequency output power despite shaft speed variations. Frequencies of 60, 400, 1,600, and possibly 3,200 cps are feasible. The frequency accuracy is the same as that of the frequency reference used.

2. The brushless Secsyn generator can be run at very high rotational speeds permitting, in many instances, direct connection to a turbine prime mover. This results in the elimination of a gear box and in a lightweight generator.

3. System ratings of 20 kva are possible with shaft speeds up to approximately 50,000 rpm. Systems of a few

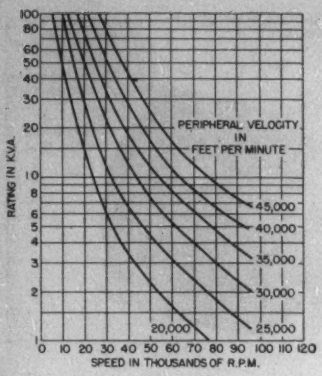


Fig. 9. Maximum ratings of brushless Secsyn generator.

kva are possible with shaft speeds of 100,000 rpm or higher.

4. System is inherently able to carry lagging reactive loads and, therefore, has motor-starting and fault-clearing capabilities.

APPLICATIONS OF THE SYSTEM

PRECISE-FREQUENCY GENERATOR systems of the type described have been built in various sizes from approximately 1 to 30 kva.

The "synchronous flux" type of variable-speed constant-frequency generator system has been described earlier.[1] This type seems to be best suited to aircraft main generator applications where the output is 20 to 120 kva, 3-phase, 400 cps, and the input shaft has a speed range of approximately 2 to 1 or 3 to 1, and a midrange speed of approximately 6,000 or 8,000 rpm.

In aircraft main generator applications, where either the output rating is smaller than about 20 kva, or where the input shaft speed is higher than present aircraft pad speeds, then the type of system described here is preferred.

In the foregoing applications the main engines are the source of mechanical power. Because of this, the speed of rotation is determined by considerations outside the generating system. There are many instances, such as emergency power units and auxiliary power units, where the speed of the prime mover can be dictated by the generator requirements. Here the system usually employs a conventional synchronous generator and the output frequency is determined by a speed governor. In this kind of application, where a frequency accuracy of 1% or better is required and where speed governing is unusually difficult, it may be preferable to regulate the shaft speed to quite wide limits and use a precise-frequency generator system of the type described.

There are other auxiliary power unit and secondary power unit applications where the speed of the prime mover is deliberately varied in order to minimize fuel consumption at reduced loads. Here, of course, a precise-frequency generator system must be used to obtain a constant output frequency.

There is a whole class of application of this precise-frequency generator system which exists because it is possible to use a very high speed generator and still obtain a comparatively low output frequency. These systems are particularly attractive where a high-speed turbine prime mover can be directly connected to the generator without the use of reduction gearing. Such a system can be built as a 60-cps power supply at a small fraction of the weight of presently available conventional 60-cps power supplies.

Finally, there is a large area of application of this precise-frequency generator system which is presently unexploited. This is in those applications where the extremely good frequency accuracy of the system is of prime importance. As has been pointed out, the system described has a frequency accuracy as good as the small frequency reference and has negligible frequency transients. So these systems offer the possibility of improvements in frequency regulation of several orders of magnitude, when utilization equipment having this sort of requirement is developed.

Appendix

DISPLACEMENT FACTOR OF THE INPUT CURRENT

The purpose of this appendix is to calculate the value of the displacement factor of the fundamental of the input current fed to the single conversion frequency changer of Fig. 2, when it is feeding a balanced 3-phase resistive load.

A rigorous mathematical treatment of this problem will not be attempted because the mathematics are too cumbersome. Instead, a number of simplifying assumptions will be made and a simple physical visualization used to arrive at the value for certain instants of time. Then a somewhat more general method, based on the same assumptions, will be used to calculate the value at the intervening instants of time.

The simplifying assumptions made are as follows:

1. The load is purely resistive and balanced.
2. The ratio of the input frequency to the output frequency is large.
3. There is no current overlap between phases.
4. The filter completely suppresses harmonic currents, so that the load current is a sine wave.

With these assumptions, the input currents of any phase are always rectangular waves having a width of 120 electrical degrees on the input frequency basis, and a height which varies from a positive maximum (equal to the peak of the output current wave) through zero to a negative maximum. The angular phase position of these rectangular waves with respect to the (sinusoidal) input voltage varies with the firing angle α. (See Fig. 11).

Consider first the instant in the output wave when the current in A phase of the load is a positive maximum. This means that the current flowing, in turn, from each of the input phases 1, 2, and 3 to the $A+$ terminal will have the maximum amplitude, and the firing angle α will be zero. Because of the balanced 3-phase load on the frequency changer, at this same instant in the output wave, the current in the B and C load phases

will both be equal to one-half amplitude in the negative direction. That is to say, the current flowing from each of the input phases, in turn, to the $B-$ and $C-$ terminals will be one half per unit, and the firing angle α will be 60 degrees ($\cos 60° = 0.5$). This instant is shown in the left-hand column of Fig. 11.

From this figure it will be noticed that the input current consists of a positive rectangle of 1.0 amplitude in phase with the supply voltage, and a negative rectangle of 1.0 amplitude which lags 60 degrees behind the supply voltage. It is a simple matter to infer that the fundamental component of such a wave lags the supply voltage by 30 degrees and, therefore, the displacement factor for this instant is cos 30° or 0.866.

Consider next a later instant in the output wave when the current in A phase of the load is 0.866 of maximum, the current in B phase is -0.866 and C phase is zero. Under these conditions, the firing angle α of each of the input phases feeding $A+$ and $B-$ terminals are both equal to 30 degrees ($\cos 30° = 0.866$). This results in the input wave shown in the center column of Fig. 11 where the amplitude of both positive and negative rectangles is 0.866, and both lag 30 degrees behind the supply voltage. Here obviously the fundamental of the input current lags 30 degrees behind the supply voltage and the displacement factor is $\cos 30° = 0.866$.

Consider finally an instant still later in the output wave when the current in A phase is $+0.5$, in B phase is -1.0, and in C phase is $+0.5$. The conditions that result at this instant are shown in the right-hand column of Fig. 11. Here the positive rectangle has 1.0 amplitude and lags 60 degrees behind the supply voltage, and the negative rectangle has 1.0 amplitude and is in phase with the supply voltage. This, once again, leads to a fundamental which lags 30 degrees behind the supply voltage and a displacement factor of 0.866.

From this visualization of three instants which cover one sixth of an output cycle, it is reasonable to conclude that the instantaneous value of the displacement factor can be expressed as a function which repeats 12 times in one complete output cycle. It is, therefore, necessary to calculate the value of the displacement factor only for every instant in the first twelfth of the output cycle, that is, for an excursion of the firing angle α of the input current to the $A+$ terminal from $\alpha = 0$ to $\alpha = 30$ degrees.

A Fourier analysis of the rectangular waves leads to the following expressions for the coefficients of the fundamental:

$$a_1 = \frac{1}{\pi}\int_{\alpha}^{\alpha+120°} \cos\alpha \cos t\, dt + \frac{1}{\pi}\int_{240°-\alpha}^{360°-\alpha} \cos(\alpha+120°) \cos t\, dt + \frac{1}{\pi}\int_{240°+\alpha}^{360°+\alpha} \cos(\alpha+240°) \cos t\, dt \quad (1)$$

$$b_1 = \frac{1}{\pi}\int_{\alpha}^{\alpha+120°} \cos\alpha \sin t\, dt + \frac{1}{\pi}\int_{240°-\alpha}^{360°-\alpha} \cos(\alpha+240°) \sin t\, dt + \frac{1}{\pi}\int_{240°+\alpha}^{360°+\alpha} \cos(\alpha+240°) \sin t\, dt \quad (2)$$

where time t is measured from the point of natural commutation, and where for each of the coefficients the first term is the $A+$ current, the second is the $B-$ current, and the third is the $C-$ current.

Performing the integrations in equations 1 and 2, the values of the coefficients are

$$a_1 = \frac{3}{4\pi}(-\sin 2\alpha + \sqrt{3} - \sqrt{3}\cos 2\alpha) \quad (3)$$

$$b_1 = \frac{3}{4\pi}\left(\frac{1}{\sqrt{3}}\sin 2\alpha + 3 + \cos 2\alpha\right) \quad (4)$$

Combining these two coefficients leads to an expression for the amplitude of the fundamental and to an expression for its displacement on the time axis

$$\text{Amplitude} = \sqrt{a_1^2 + b_1^2} \quad (5)$$

$$\text{Displacement} = \delta = \tan^{-1}\frac{a_1}{b_1} \quad (6)$$

The electrical phase displacement between this fundamental of the current and the supply voltage is

$$\text{Electrical Displacement} = \frac{\pi}{6} - \delta \quad (7)$$

The displacement factor is the cosine of this angle and is given by the following expression:

$$\text{Displacement Factor} = \frac{3}{\sqrt{11 + 2\cos(60° - 4\alpha)}} \quad (8)$$

This expression gives a value of 0.866 at $\alpha = 0$ and $\alpha = 30$ degrees which agrees with the values obtained previously by visualization. At intermediate angles, it gives lower values, the lowest being 0.833 at $\alpha = 15$ degrees.

In order to arrive at an average value of the displacement factor, we use the expression

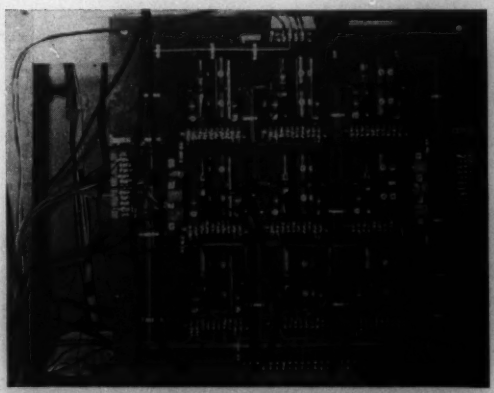


Fig. 10. Breadboard model of frequency changer using 16-ampere p-n-p-n switches.

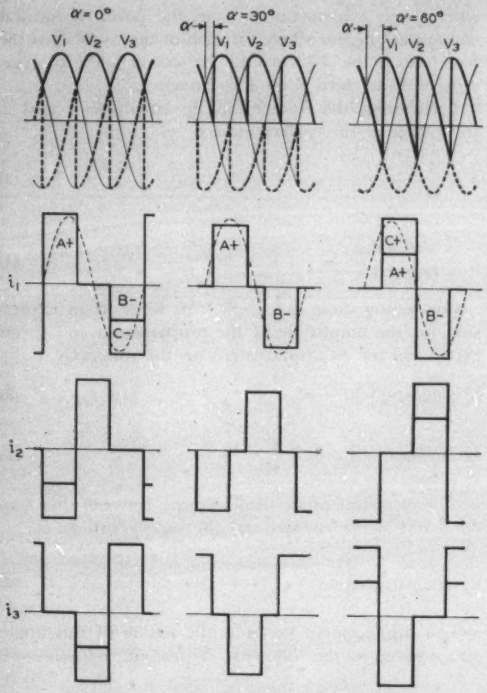


Fig. 11. Idealized input-current waveshapes.

$$\text{Average Displacement} = \frac{18}{\sqrt{13}\,\pi}\int_0^{30^\circ} \frac{d\alpha}{\sqrt{1-\left(\frac{2}{\sqrt{13}}\right)^2 \sin^2(30^\circ - 2\alpha)}}, \tag{9}$$

This expression leads to an elliptical integral which, when evaluated, gives a value of 0.843 for the average displacement factor.

Von Issendorff,[9] by assuming an infinite number of input phases, performs similar calculations for the whole range of output load power factors and for the whole range of output voltage reductions by phase delay. The value 0.843 derived in the foregoing agrees with Von Issendorff.

REFERENCES

1. Variable-Speed Constant-Frequency Generator System for Aircraft, K. M. Chirgwin, L. J. Stratton. AIEE *Transactions*, pt. II *(Applications and Industry)*, vol. 78, Nov. 1959, pp. 304-10.

2. Mercury-Arc Power Converters in North America, AIEE Committee Report. *Ibid.*, vol. 67, pt. II, 1948, pp. 1031-59.

3. An Asynchronous System of Static Frequency Conversion for the Supply of Low-Frequency Traction Networks (in German), M. Schenkel. *Elecktrische Bahnen*, Munich, Germany, vol. 8, 1932, pp. 69-73.

4. Step-Up Frequency Changer, R. J. Wurm, L. J. Stratton. AIEE *Transactions*, pt. II *(Applications and Industry)*, vol. 79, 1960 (paper no. 60-1049).

5. A Silicon Controlled Rectifier—Its Characteristics and Ratings, D. K. Bisson, R. F. Dyer. *Ibid.*, vol. 78, May 1959, pp. 102-06.

6. Mercury Arc Power Rectifiers (book), O. K. Marti, H. Winograd. McGraw-Hill Book Company, Inc., New York, N. Y., 1930.

7. Effect of Operating Frequency on the Weight and Other Characteristics of Missile Alternators and Transformers, R. E. Turkington. AIEE *Transactions*, pt. II *(Applications and Industry)*, vol. 77, Nov. 1958, pp. 289-300.

8. Dynamo-Electric Machine, A. Bekey, H. M. Robinson. *U. S. Patent no. 2,796,542*, June 18, 1957.

9. The Grid-Controlled Converter (in German), J. Von Issendorff. *Wissenschaftliche Veroffentlichungen aus den Siemens-Werken*, Berlin, Germany, vol. 14, pt. III, 1935, pp. 1-31.

SF_6 Circuit Breaker Delivered

Shown at the beginning of a rail journey to the Pennsylvania Power & Light Company's new Brunner Island steam–electric generating station on the Susquehanna River near Harrisburg, Pa., this huge 230-kv 15,000-mva Westinghouse Electric Corporation circuit breaker was shipped fully assembled, with bushings in place. This was Westinghouse's first order for a 230-kv breaker in which sulfur hexafluoride (SF_6) was specified as the interrupting medium.

At Brunner Island, Pennsylvania Power & Light is now using the breaker as one of two units (the other is a conventional Westinghouse oil circuit breaker) protecting 45 miles of 230-kv transmission circuits to its West Shore and South Akron substations.

With continuous capacity of 1,600 amperes at 230 kv, the breaker has dead-tank construction mounted on common base beams, positive mechanical connections between all contacts and operating mechanisms, and bushing-type current transformers. Requirements for foundation construction are similar to those of air breakers; however, since the unit does not exhaust to the atmosphere, it avoids the noise problems of air breakers.

Application of Cryogenics to Electrical and Electronic Design

R. J. ALLEN

The study of cryogenics—the science concerned with very low temperature environments—is rapidly entering the realm of practicality. Some of the low-temperature phenomena pertinent to the field of electrical and electronic design are discussed.

CRYOGENICS is a science concerned with the very low temperature environment, extending from a high of 77 degrees Kelvin (K) or −196 degrees centigrade (C), where liquid nitrogen boils at standard pressure, down to absolute zero (0 K or −273 C). This region has come to be associated with rockets, many of which carry large quantities of liquefied hydrogen and oxygen as propellants.

Aside from the need to design electric systems for rockets, the cryogenic region may, at first, seem foreign to the electrical designer. However, since material properties and component behavior are remarkably altered in the ultracold environment, cryogenics actually holds great promise for both the electrical and electronic technology.

It is the intent of this article to outline in some breadth the background of cryogenic electronics (sometimes referred to as cryotronics), and to indicate the potential application of cryogenics to electric power system design of the future.

Research workers have done much to extend the application of low-temperature environments in physical electronics through development of masers, superconductive gyros, cooled infrared detectors, and a family of superconductive electronic components. These devices derive improved performance from the low temperature and, in many cases, their operation depends on phenomena unique at low temperature. Several can operate only within a few degrees of absolute zero, an environment which is provided by operating immersed in, or in thermal contact with, liquid helium. Helium, the last gas to become liquid, does so at 4.2 K.

A third feature encouraging the electrical designer to make use of low temperature is the relative ease with which it can be provided and maintained, thanks to recent advances. The Collins liquefier (Arthur D. Little, Inc., Cambridge, Mass.) has made liquid helium a fairly conventional laboratory tool, with well over a hundred in operation throughout the world. Present work is being directed toward smaller units, and closed-cycle liquefiers which could be used on airborne and rocket vehicles. The Zotos liquefier being developed by The Martin Company is designed to have a 25-watt cooling capacity at 2 K, while weighing under 80 pounds. A prototype unit is now being evaluated. Liquefiers of this type, with cooling capacities far larger than envisioned to be necessary for conceivable cryotronic circuitry, move the low-temperature environment out of its laboratory status and into practical usage.

Another means of providing the environment is with passive cooling, whereby the circuitry and cooling fluid are stored in Thermos-like containers called cryostats. Liquid helium is normally stored in this manner, surrounded by a second similar container of liquid nitrogen which serves as an insulator. Progress in insulation has recently permitted design of helium cryostats without the nitrogen jacket. As the conventional transportable cryostats have about a 1% per day boil-off, the helium would last 3 months, ample for most applications. A large liquid hydrogen tank (boiling point 20 K) has a boil-off rate of under 10% per year.[1] The lower ambient temperatures which might be encountered in space would improve these figures, assisting in long flights. Since liquid helium has a density of about 1/10 that of water, and since the insulation is also of low density, the weight of even a reasonably large passive cryostat is not excessive.

The temperature of the fluid in passive cryostats may be controlled through the boiling point–pressure relationship. Thus if the pressure is reduced, the temperature is also reduced. By regulating the pressure, temperatures of below 2 K can be obtained with liquid helium. At high altitude, the low-pressure sink is provided without additional equipment, as shown in Table I.

Table I. Relationship of Altitude, Pressure, and Helium Boiling Temperature

Altitude, feet	Pressure, millimeters of Hg	Helium Boiling Temperature, degrees K
0	760	4.21
5,000	632	4.02
10,000	522	3.84
20,000	349	3.48
30,000	226	3.15
40,000	141	2.82
50,000	87	2.56
60,000	54	2.32
70,000	34	2.13
80,000	21	1.96
90,000	13	1.81
100,000	8	1.68

Full text of paper 60-1035, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee. Scheduled for publication in AIEE *Applications and Industry*, Jan. 1961.

R. J. Allen is with The Martin Company, Baltimore, Md.

While the cryogenic equivalent is not considered a practical replacement for single isolated conventional circuits, a crossover point does occur as circuitry complexity increases, above which the cryogenic circuitry gives an improvement in size and weight as well as reliability. It is in the interest of moving this crossover point down or, similarly, of making more of the necessary functions suitable for cryogenic operation that we should also investigate the extension of cryogenic techniques to the electrical portions of an over-all system. Since the low temperature may be available in some design areas, and in fact may already be in use by various electronic components, it seems logical to investigate its possibilities for improvement in electric system design and in integrating the electric system more closely with cryogenic electronic or control systems.

LOW-TEMPERATURE ELECTRICAL PHENOMENA

In considering the field of cryogenic phenomena of use in electrical design, we have the quite obvious extension of room temperature thermal effects. There is the decrease in resistivity of copper, for example, which allows a no. 40 wire to carry easily 4 amperes, which exceeds twice its fusing current at room temperature. Thermal noise encountered in all resistance also decreases, giving greater receiver sensitivity. Semiconductors, such as silicon and germanium, provide a material with high thermal conductivity (2.5 watts per centimeter per degree K for germanium at 4 K) while having electrical conductivity as low as most conventional insulating materials.[2,3] Lead, a material having little resiliency at room temperature, becomes progressively better until, near liquid helium temperature, it acts much like spring steel. These and many other effects are but continuations and natural extensions of phenomena present at room temperature. They by no means reveal the phenomena occurring only at low temperature which give cryogenics its great promise in electronic and electrical design. This promise centers mainly around the phenomena of superconductivity and its associated magnetic effects.

Superconductivity is not a new phenomenon, having been discovered by Onnes at Leyden in 1911.[4] Onnes, who first succeeded in liquefying helium 2 years earlier, was investigating the low-temperature resistivity of mercury. He found its resistance underwent an abrupt transition to zero at 4.2 K, the material entering the state he named "superconductivity." A similar effect has been found in 21 other metals and many alloys. An abbreviated list of elements and the temperature at which they become superconducting is given in Table II. That the resistance is exactly zero below the transition was pointed out quite dramatically by Collins of the Massachusetts Institute of Technology. He induced a current in a ring of superconducting lead in March 1954. The current decay in a simple RL series path of normal conductivity is expressed by

$$I = I_0 \epsilon^{-RT/L} \tag{1}$$

However, if the material is superconducting, making R equal to zero, the time dependency will be lost, the exponential term will equal 1, and I will remain equal to I_0. When Collins terminated his experiment in September 1956, the current was still equal to that induced to an accuracy of 1 part in 10^{11}, suggesting that the resistance is effectively zero.

Of equal importance with zero resistivity are the magnetic effects associated with superconductivity. One is that a superconductor is diamagnetic. Except for a slight penetration similar to skin effect at high frequency in conventional conductors, there is no magnetic flux within a superconductor. A corollary is that current flow in a superconductor is a surface effect lying no deeper than the penetration depth. The internal flux and current of a normal conductor are expelled as the conductor enters the superconducting state.

During his experiments with superconductors, Onnes also discovered that there is a limit to the current which could be put through a superconductor without restoring it to its normal resistive state. It was later shown that it is the magnetic field produced by the current which destroys superconductivity.[5] The magnetic-field dependence of the superconductive state was thus revealed. The actual critical field intensity required to destroy superconductivity H_c varies with the conducting material and is related to the temperature by the equation

$$H_c = H_0 \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

where H_0 is the extrapolated value of the critical field at absolute zero as given in Table II. A plot of H_c vs. T is given in Fig. 1.

With these phenomena—superconductivity and the associated magnetic effects—we may begin to consider application to electrical functions.

Table II. Sample Superconducting Transition Temperatures and Critical Magnetic Fields

Element	Transition Temperature T_c, degrees K	Critical Field H_0 (at $T = 0$), oersteds
Technetium	11.2	—
Niobium	8.0	1,960
Lead	7.2	800
Vanadium	5.1	1,340
Tantalum	4.4	860
Mercury	4.2	415
Tin	3.7	310
Indium	3.4	275
Aluminum	1.2	106

APPLICATION TO ELECTRONIC AND ELECTRIC EQUIPMENT

Energy and Signal Storage. An immediate application of the superconducting ring just described is to the storage of electric energy, as evidenced by Collins' experiment. A further investigation of this lossless current flow, termed a "persistent current," discloses an interesting effect.

If we consider a superconducting ring with a current flowing around it, it is evident that since the resistance

is zero, there is no potential difference along the conductor. Referring to Maxwell's relation

$$\oint_c E\,ds = \iint_s \frac{\partial B}{\partial t}\,dA$$

and, since $E = 0$,

$$\oint_c E\,ds = 0$$

Then

$$\iint_s \frac{\partial B}{\partial t}\,dA = 0$$

which indicates that

$$\frac{\partial B}{\partial t} = 0$$

There can thus be no change in the magnetic field B through the ring while it is superconductive. Should an external source, such as a magnet or a coil, supply the field while the ring is being lowered below the transition temperature, and should this external field then be removed while the ring is superconducting, a current will be induced in the ring of the correct direction and amplitude to set up a flux through the ring equal to the flux lost upon removal of the external field. This is given by the expression[6]

$$L\frac{di}{dt} - \pi b^2 \frac{dH_e}{dt} = 0$$

where L = self-inductance of ring; H_e = external magnetic field normal to ring; and b = ring radius.

The energy stored in the current flow may be found by first integrating the expression

$$Li = \pi b^2 (H_e - H_i)$$

where H_i = the value of the field when there was no current in the ring. Thus, the ring cooled in the presence of a magnetic field H_i, which is then reduced to zero after the ring superconducts ($H_e = 0$), carries a current of

$$i = \frac{\pi b^2 H_i}{L}$$

giving an energy storage of

$$E = 1/2\ L\ I^2 = \frac{[\pi b^2 H_i]^2}{2L}$$

This energy could be extracted by putting a small winding around a portion of the ring, which shunts the load. By making a section of the ring resistive, having a magnitude equal to that of the load, the current would then dissipate in the combined parallel resistance at the ring and load at a rate governed by the L/R time constant. The current flow to the load would be kept quite uniform by varying the resistance in the ring to change the time constant during discharge.

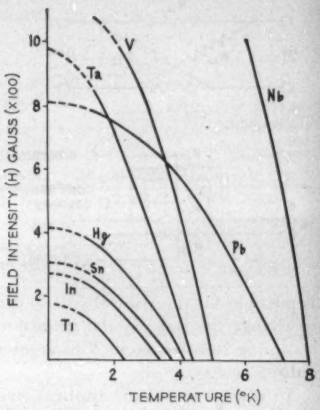


Fig. 1. Threshold magnetic fields vs. temperature for some superconducting elements.

On a much smaller scale, such a device can serve as a memory unit. The current stored in the ring may be in either a clockwise or counterclockwise direction depending on the direction of the input current which caused it to be induced.[3] The sense of the input current gives the binary information to be stored, either a one or a zero. Research is currently being done on several thin-film devices based on this effect for application as computer memory devices.

The cryotron, developed by Buck,[7] provides a very simple switch or relay. A superconductor may be considered a closed circuit. If a magnetic field is placed around the superconductor, it will return to the normal state corresponding to the open circuit. The original configuration, consisting of a coil wound along the conductor which undergoes the transition, has been refined to a thin-film construction. The coil has been reduced to a straight conductor, crossing but insulated from the transition material.

If the transition material is chosen to become superconductive just above the operating temperature (such as tin operating at 3.6 K), it may be seen from Fig. 1 that only a small field is required to return it to the normal state. If the control coil, or its equivalent is of a material such as lead, which becomes superconducting at a much higher temperature and thus has a higher critical field intensity at the operating temperature, it

Fig. 2. Superconducting reversing switch.

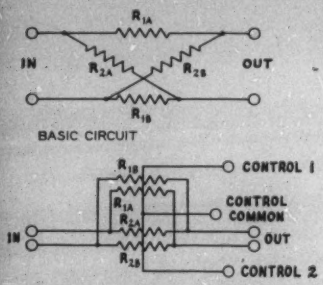


Fig. 3. Circuit layout of superconducting reversing switch.

is possible for the control coil to carry enough current to change the state of the transition material without becoming resistive itself. This is the normal design procedure.

An illustration of the application of these techniques is given in Figs. 2 and 3, which show a double-pole double-throw reversing switch. By steering a current in either direction, this circuit would serve as the input control circuit for the memory rings discussed previously in addition to its conventional relay applications. If neither path is made resistive, the switch acts as a short circuit across the load.

Rectification and Amplification. Several techniques have proved workable in the area of a-c to d-c conversion. A full-wave single-phase rectifier designed by Olsen is presented in Fig. 4.[8] The a-c input is transformer-coupled into a push-pull rectifier circuit. The coils CC' are biased magnetically by a direct current through coils FF' to just below their transition field value. Then one coil on each half cycle of the alternating current, assume coil C, has a field induced, due to the current through it, which aids that produced by coil F. The sum of these fields is sufficient to cause C to become resistive. No current will then flow through except the small value needed to increase its field to the critical point. However, the current through coil C' creates a field in opposition to that produced by F'. The resultant field is their difference, causing coil C' to remain superconducting. It then carries the current. On the following half cycle, the fields in CC' are reversed. C' becomes resistive and C carries the current.. The effecitve diode action of coils CC' thus provides a full-wave rectified current across the load.

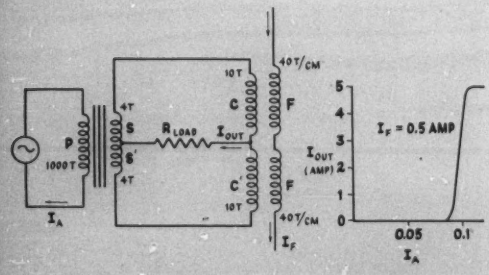


Fig. 4. Superconductive rectifier and amplifier, Olsen.

Some of the constructional and operational details of this circuit might be of interest, as shown in Fig 3. The wire used was ordinary solder, drawn to a 0.6-mm diameter. As shown on the curve, the circuit gave a current gain of 10. Adapted to a voltage amplifier, it had a gain of 200. The maximum output current is calculated to be 200 amperes. Load resistance was on the order of 0.2 milliohm, low by conventional standards, but quite typical of cryogenic circuits.

A second rectifier, a full-wave bridge patented 12 years ago, may be of interest for its rather unusual geometry.[9] As shown in Fig. 5, it consists of a hollow superconducting ring with four leads symmetrically attached and a field-regulating lead run inside the hollow ring.

A direct current is run through the field-regulating lead of sufficient intensity that its magnetic field is slightly higher than that required to destroy superconductivity in the ring. If an alternating current is applied to a pair of opposite leads on the ring, the current trying to flow on the ring sets up fields, which in one direction aid, and in the other direction oppose, the d-c field in much the same manner as in the previous circuit. The opposing fields give a resultant field below the critical value, providing a preferential path for current flow. On the following a-c half cycle the a-c fields reverse and the current flows through the other path. Full-wave rectification is thus obtained.

Transformers and Rotating Machinery. Of primary interest is the d-c transformer, to which cryogenics imparts high efficiency and the qualities of thermal isolation. By way of illustration, let us consider a conventional transformer, assumed to be lossless. If direct current is applied to the primary, a current is generated in the secondary which then decays exponentially according to equation 1. However, if we now return to superconductive circuitry, and consider the superconducting transformer to be loaded with a superconductor, the current dissipation expression follows the same logic as that for the persistent current loop. Since R is zero, there is no dissipation and the current will remain constant indefinitely or until the transformer input is varied.

Operated in the superconductive state, transformers have no I^2R loss, giving a high efficiency. The high current capacity of the windings could greatly reduce their size and weight, and that of the core.

With cryogenics, a transformer can be used to provide thermal as well as electrical isolation. One of the large heat inputs to cryogenic components is through the electric leads. While this can be minimized by proper design, further improvement is possible by coupling in the power with transformers employing low thermal conductivity coil forms.

Consideration of transformers leads to the subject of rotating machinery, where superconductive windings give greatly improved efficiency. Standard fractional horsepower motors have been run successfully in liquid helium, with bearing modifications. One of the main

problems with ball bearings is that of the abrasive action of solid air. Sleeve bearings of Teflon work quite well. A few other possibilities are also of interest.

Machinery rotating in a fluid is subject to viscous drag similar to the windage of an air environment. An interesting effect occurs in liquid helium (isotope 4) just above 2.1 K, where the helium undergoes a phase change. Below this point, termed phase II, the helium exhibits no viscosity, and almost infinite thermal conductivity. The drag then ceases.

Motor applications in such an environment would include inertial reference, servos, cavity tuning, and *IR* collection optics.

The superconductive gyro will be passed over, inasmuch as it has been treated at considerable length elsewhere. One feature of direct application to rotating equipment is the frictionless bearing made possible by floating the rotor in a magnetic field.

Control and Regulating Circuitry. The superconducting transition provides an extremely sensitive region for detecting small variations in magnetic fields or in temperature. By shielding sensors from magnetic fields, the system temperature may be sensed and controlled. This thermal sensing may also be done with semiconductors, which show a large increase in resistivity with small decreases in temperature. With the constant temperature environment thus assured, magnetic field sensors will not be subject to errors through temperature variations.

In cryogenic electronic and electric circuitry, it is current flow which is the more important power supply parameter, since the voltage is very low because of the low resistance of the circuitry, and the circuits are connected in series. The operation of most cryogenic electronic and electric circuitry depends upon constant current supplies. Electronic circuitry normally operates at from 40 to 300 milliamperes. Electric equipment can carry about 200 amperes maximum with pure lead conductors. As alloys often have higher critical values, continued research into superconducting alloys may increase the current capacity.

An example of a magnetic sensor, and thereby a current sensor, is given in Fig. 6. This device, an offshoot of some bolometer development at The Martin Company, is still in the development stage, as indicated by the rather large size. The operation of these sensors is quite simple. The transition from the normal to superconducting state is not discontinuous. There is, rather, a linear scope to the transition, the steepness of which may be varied by alloy composition bias current or magnetic-field orientation. If the sensor is operated with its quiescent point near the middle of the linear range, there will be a large change in resistance for a slight change in input signal, either magnetic or thermal.

An interesting feature of this sensor is the heat sink. The sensor is a thin film of tin which requires support. It is deposited on a block of material which also serves to conduct heat out of the sensor, reducing thermal

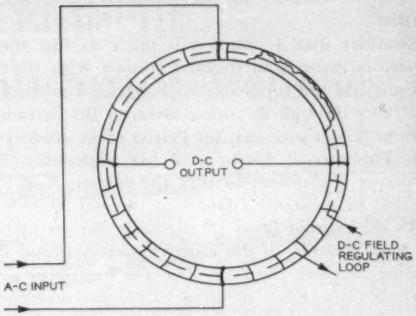


Fig. 5. Superconducting bridge rectifier, Ericsson.

lag. Since the device measures current or associated magnetic field by a magnetoresistive effect, rather than by a thermoresistive effect, there is no need or desire for the sensing element to change temperature. In a normal device, the heat sink, such as copper, is a good electric conductor also and therefore must be insulated from the sensor to avoid shunting it. The insulation is a poor thermal conductor and thus limits the speed of the sensor. In this cryogenic device, germanium with a minimum impurity content is used as the heat sink, and the insulation layer is omitted. At low temperature, the resistivity of germanium becomes quite high, providing electrical insulation, while the thermal conductivity is also high, as mentioned previously, giving good thermal response. A device like that shown has been found through analog techniques to have a response of better than 3 mc.

There are several cryogenic approaches to design of frequency references and oscillation is current sensitive. This may suggest another method of current measurement, using discriminator techniques. Here, the signal related to the current magnitude, being an a-c signal, could be transformer-coupled to room temperature to provide control for room temperature equipment.

The Peltier effect at a superconducting junction was proposed by Kahn of the Research Institute for Advanced Studies, Baltimore, Md., as the basis for a relaxation oscillator. It has been found that dissimilar metallic junctions undergo a change in their Peltier voltage when one metal becomes superconducting. The voltage becomes zero at the transition temperature and remains

Fig. 6. Magnetoresistive current sensor.

at zero or reverses as the temperature is decreased further.

Consider that a junction is made so that the nonsuperconductor is in thermal contact with the liquid helium and the superconductor part is cooled only by heat flow through the other metal to the helium. The current flow is such that the Peltier effect produces cooling. The current source is of low impedance (if the oscillator is shunted) so that the current flow will be affected by resistance changes in the oscillator.

As the current flows through the device, there will be Joule heating in the resistive materials and Peltier cooling at their junction. The cooling outweighs the heating, causing one material to become superconducting. The Peltier effect will then change, producing less cooling, while the current will increase due to the resistance decrease. The Joule heating will then cause the junction to warm up and cease superconducting. The current will then decrease and the Peltier cooling will again cool the junction, repeating the cycle. The speed of oscillation is dependent on the current and the thermal response of the oscillator. The thermal-response time may be kept constant, giving an output frequency proportional to the current flow.

Frequency standards may be based on the previous oscillator techniques, using constant current sources provided by the magnetic sensor current controls, also described previously. The parallel *L-C* tank circuit provides a good frequency standard through its high *Q* due to the low *R* and its high dimensional stability at constant low temperatures. Resonant cavities have been employed in much of the experimental work on superconducting phenomena at high frequencies on the order of 30 kmc. Cavities with *Q* of 600,000 have been obtained.

Further Possibilities. The areas in which cryogenic electric devices may be utilized in replacement of the conventional devices embrace much of the electrical field where the currents or fields are not extremely high. With little or no power dissipation, the small wiring permitted may suggest techniques of printed or vacuum-deposited wiring and components. Since a magnetic field below the critical value does not penetrate a superconductor, magnetic shields may be printed or deposited in thicknesses of less than 0.0001 inch, shielding adjacent circuitry. Components and circuitry can be made together automatically.

CONCLUSIONS

THE STUDY of cryogenics and cryotronics, long a laboratory oddity, is rapidly entering the realm of practicality. The biggest obstacle—creating and maintaining the environment—already has been lessened, and it will be removed with the imminent arrival of small closed-loop cryostats and other developments. The task then will be to exploit the unusual cryogenic phenomena, thereby bringing about improved size, weight capability, and reliability of electric and electronic equipment.

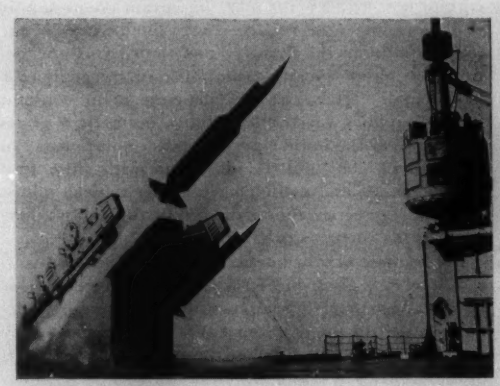
Buck, in an unpublished paper, has predicted cryogenic circuits with more than 10^{10} components assembled in a cubic inch, a density greater than that of brain cells.[10] Thus, a present-day room-sized computer could easily be contained within a package no bigger than a golf ball.

Some of the early avenues this development is likely to follow have been touched upon in this article. By placing parallel attention on electrical and electronic aspects, we can look forward to the attainment of completely integrated and optimized cryogenic systems.

REFERENCES

1. Low Temperature Technology—What's the Latest? *Chemical Engineering*, New York, N. Y., Nov. 30, 1959.
2. Thermal Conductivity of Silicon and Germanium. *Cryogenic Data Sheet 3.142.2*, U. S. Bureau of Standards, Boulder, Colo.
3. Low Temperature Physics and Chemistry (book), J. Dillinger. University of Wisconsin Press, Madison, Wis., 1958.
4. H. K. Onnes. *Communications from the Physical Laboratory*, University of Leiden, Leiden, Netherlands, Supplement 34, 1913.
5. H. K. Onnes. *Ibid.*, 1914, p. 139ff.
6. Superconductivity (book), D. Shoenberg. Cambridge University Press, Cambridge, England, 1952.
7. The Cryotron—A Superconductive Computer Component, D. Buck. *Proceedings*, Institute of Radio Engineers, New York, N. Y., vol. 44, no. 4, Apr. 1956.
8. Superconducting Rectifier and Amplifier, J. L. Olsen. *Review of Scientific Instruments*, New York, N. Y., vol. 29, no. 6, June 1948.
9. Rectifier and Converter Using Superconduction, E. Ericsson, et al. *U. S. Patent no. 2,666,884*, Jan. 19, 1954.

Antiaircraft Missile



Aboard the *USS Norton Sound*, a high-performance Tartar surface-to-air guided missile leaps from its launcher and streaks toward its target off the Pacific Coast. Tartar, produced for the U. S. Navy's Bureau of Naval Weapons by the Convair-Pomona (Calif.) Division of General Dynamics Corporation, will be the primary antiaircraft weapon on destroyers as well as a secondary weapon on cruisers. It is about 15 feet long and a foot in diameter. Distant aerial targets are detected by radar and are sought out and destroyed by Tartar.

Prediction of Transient Thermal Environments in Space Vehicles

TAKAO ISHIMOTO

B. W. RANDOLPH

In this article, transient thermal envelopes induced within space vehicles by conditions external to the earth's atmosphere are considered. A simple method for predicting transient "thin" isothermal shell temperatures is presented.

WITH THE ADVENT of space vehicles, information regarding the induced environmental envelopes for equipment within the various space vehicles has become of considerable importance not only from the design standpoint, but also from the standpoint of reliability prediction. This article is concerned with that transient thermal envelope which is induced by the thermal environmental conditions encountered by satellite vehicles external to the earth's atmosphere.

Many studies regarding the thermal behavior of orbiting vehicles have been reported, but because of the complex nature of the geometric relationships between the vehicle and radiative sources and sinks, these studies have been confined chiefly to steady-state (equilibrium) considerations. The present study is concerned with a simple general method of estimating the transient surface temperature of the "thin" isothermal shell of a space vehicle.

PHYSICAL CONSIDERATIONS

THE TEMPERATURE of the space vehicle beyond the earth's atmosphere will be determined by the radiation absorbed and the heat generated and reradiated. The factors that influence the skin temperature of a space vehicle are: (1) orbital characteristics; (2) surface characteristics, especially spectral emissivities and absorptivities of the outer and inner skin surfaces; (3) the attitude of the momentum vector of a spinning satellite to the direction of the sun; (4) the attitude of the spin axis to the direction of the sun; (5) the attitude of the space vehicle and attitude of the momentum vector to the center of the earth, moon, or other solar objects; (6) heat capacity of skin and instruments; (7) conductive and radiative heat transfer from inner skin; (8) internal heat dissipation of equipment; and (9) environmental conditions, such as solar constant, albedo, and infrared radiation of earth. Studies which incorporate some of the factors listed above are cited in references 1 through 9.

Sources and Sinks. Beyond the earth's atmosphere, the only important mode of heat transfer external to the vehicle is thermal radiation. Certainly, one of the most important parameters in the thermal environment is the electromagnetic radiation from the sun. The sun is important not only as a direct source of energy but also when its radiation is reflected, e.g., from the earth's surface. These energy inputs to the vehicle may be supplemented by radiation from the earth or other natural satellites such as the moon and other planets, stellar radiation, and by collision with free molecules. These energy sources will now be discussed separately.

Solar Radiation. In general, the sun will represent a point source of energy to the space vehicle such that its intensity is governed by the inverse square law. For thermal consideration, it is important to note that the equivalent black-body temperature of the sun is approximately 10,700 R (degrees Rankine). This means that the sun radiates thermally in the short wavelength region (98% below 3 microns and 65% below 1 micron). The amount of direct solar radiation absorbed by a vehicle is a function of the spectral surface characteristics, the geometry of the vehicle and its orientation with the sun.[9-11]

Reflected Solar Radiation. The reflected solar radiation from the earth or the moon is much more difficult to represent mathematically. In general, the description of reflected radiation is based on a highly idealized model of the physical system. For example, one method to estimate the magnitude of the reflected solar energy is to assume that the total reflected energy from the earth is uniformly distributed over the hemisphere. Formulas for reflected solar radiation are available,[1,2] as is information on surface characteristics of space vehicles.[3,4]

Thermal Radiation from Earth. The equivalent black body temperature of the earth has been estimated to be 450 R. Hence, the earth and its atmosphere represent a relatively warm body in the universe. For simple vehicle geometries, the shape factor from the earth to the vehicle at a given position may be readily determined. However, the inclusion of the orbital time varying characteristics will complicate the expression considerably.

Stellar Radiation. The thermal input resulting from stellar radiation is negligible.

Collision Energy. The amount of heat generated by collisions with free molecules or the collection of ionized gases by the vehicle is negligible. The magnitude of this energy is estimated not to exceed 0.03 Btu per hour per square foot.

Full text of a conference paper presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

Takao Ishimoto is with the Hughes Aircraft Company, Culver City, Calif.; B. W. Randolph, formerly with Hughes Aircraft Company, is now with the Northronics Division of Northrop Corporation, Hawthorne, Calif.

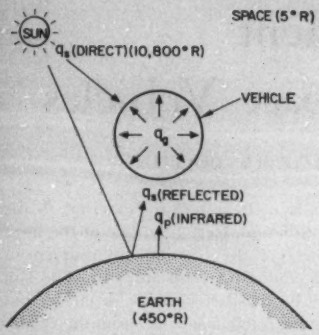


Fig. 1. Thermal environment of a space vehicle.

Space as a Sink. The black-body temperature of space has been estimated to be equivalent to 5 R which, for all practical computational purposes, represents an enveloping body of zero degrees absolute temperature with infinite heat capacity.

A schematic representation of the sources and sinks is shown in Fig. 1.

MATHEMATICAL DEVELOPMENT

General Considerations. The term "thin" as utilized in the present development denotes a shell with a zero temperature gradient across its thickness. In many cases, this idealization approximates closely the physical situation. It is apparent that a finite shell which represents the physical situation will behave at short times like a semi-infinite slab, whereas for longer periods of time it may be treated as isothermal. Some quantitative information regarding this transition from semi-infinite to isothermal behavior is available.[12]

Representation of the Heating Function. In the present study, the source contributions are grouped together and represented by a single symbol $q(t)$. Representation of the over-all heat input by a single function does not imply that it is easy to evaluate; on the contrary, it is quite difficult to evaluate exactly. This grouping is used to facilitate the mathematical analysis as well as to enable presentation of numerical results. The heating function q may be represented symbolically as follows:

$$q = q_{sd} + q_{sr} + q_p + q_g \tag{1}$$

where

q_{sd} = direct solar radiation absorbed
q_{sr} = reflected solar radiation absorbed
q_p = direct planet radiation absorbed
q_g = heat internally generated and absorbed

In general, these four sources do not have to be considered simultaneously. Equation 1 represents the flux on a differential area of the shell. For an isothermal shell of finite area, the projected areas of the vehicle must be employed. The heating function is then represented as:

$$q = (1/A_v)\,(q_{sd}\,A_{sd} + q_{sr}\,A_{sr} + q_p\,A_p + q_g\,A_v) \tag{2}$$

where

A_v = surface area of the vehicle
A_{sd} = projected area relative to direct solar radiation
A_{sr} = projected area relative to reflected solar radiation
A_p = projected area relative to radiation from the planet

Representation of Nonisothermal Shells. If it is further assumed that the thermal properties are invariant with temperature, a heat balance on a differential area of a shell will yield a partial differential equation in two space variables. However, the resultant expression does not readily yield to analytical methods; usually, numerical techniques are employed.

A recent presentation indicates that a computer program has been developed for handling problems of this type as well as 2- and 3-dimensional parabolic equations.[13]

Isothermal Shells. The heat balance equation for an isothermal shell is represented by the following expression:

$$Q = qA_v = \sigma\,\epsilon\,A_v T_1^4 + m\,C_p\,\frac{dT_1}{dt_1} \tag{3}$$

where the initial conditions are $t = 0$ and $T_1 = T_0$.

It is convenient to nondimensionalize equation 3 by using the following definitions:

$$T = T_1/T_0$$

$$t = t_1\,(\sigma\,\epsilon\,T_0^3/\gamma\,C_b b)$$

$$\psi = \beta^4 = q/(\sigma\,\epsilon\,T_0^4) \tag{4}$$

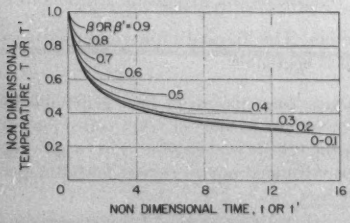
Use of equation 4 yields an equation with a single parameter

$$\frac{dT}{dt} + T^4 = \psi = \beta^4 \tag{5}$$

with

$$t = 0,\ T = 1$$

In general, ψ will be a complex function of time due to the nature of q. The solution for step input heating function will be presented in the paragraphs which follow. This will be followed by a simple method of ap-



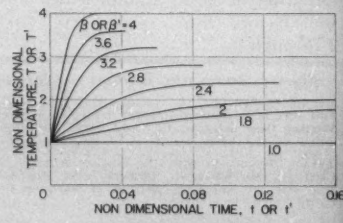
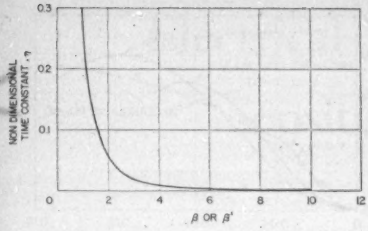


Fig. 2 (*left* and *right*). Thermal response of a thin isothermal shell with step input heating function, for various parametric values.



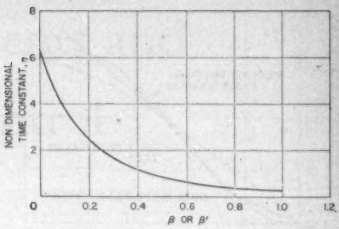


Fig. 3 (*left* and *right*). Thermal inertia characteristics of a thin isothermal shell with step input heating function, for various parametric values.

proximating the response for an arbitrary heating function.

Step Input Heating Function. For a step input heating function, the response of the thin isothermal shell is obtained readily by simple quadrature. Although the solution is an inconvenient form with the independent variable t, expressed in terms of the dependent variable T, it is useful as it represents an exact solution in a closed form. The solution is expressed as

$$t = \frac{1}{2\,\beta^3}\left\{\tan^{-1}\left[\frac{(T-1)}{\beta^2+T}\right] + \frac{1}{2}\ln\left[\frac{(T-\beta)\,(1+\beta)}{(T+\beta)\,(1-\beta)}\right]\right\} \qquad (6)$$

When $\psi = 0$, the solution as expressed by equation 6 reduces to

$$T = \frac{1}{(3\,t+1)^{1/3}} \qquad (7)$$

Numerical values for a range of typical parametric values are presented in Fig. 2.

The thermal inertia characteristics of the system are described by the time constant of the system. Although the time constant is defined in many ways, a common definition is the elapsed time to $(1 - \varepsilon^{-1})$ of the peak temperature rise. This measure of the thermal inertia effect of the system is used here. A plot of the time constant η as a function of the characteristic parameter of the system is presented in Fig. 3.

Arbitrary Heating Function. When the heating function can be approximated adequately by a mathematical function, analytical techniques are available.[14] Certainly for linear systems, the response may be expressed in terms of a convolution integral. In general, these methods are quite involved and tedious as means of obtaining numerical answers. The present discussion proposes an alternative method.

Suppose the heating function is represented by the curve shown in Fig. 4. The heating function is represented by a series of rectangular pulses. The intervals can be chosen small enough so that sufficiently accurate representation may be achieved. Suppose the heating function is approximated by the succession of rectangular pulses shown in Fig. 4. In the time interval from t_0 to t_1, the step input solution as represented by equation 6 may be used to determine the response characteristics. In the succeeding intervals, the initial conditions in general are not represented by $T_0 = 1$. Hence, the solution as represented by equation 6 cannot be used directly. Two things may be done to modify equation 6 in order to account for the varying initial conditions: an arbitrary constant T, which represents the initial conditions, may be used in equation 6 with the defined variables unchanged as shown in equation 8, or equation 6 may be used with redefined variables as shown in equation 9.

$$t = \frac{1}{2\,\beta^2}\left\{\tan^{-1}\left[\frac{\beta\,(T-T_i)}{\beta^2+TT_i}\right] + \frac{1}{2}\ln\left[\frac{(T-\beta)\,(T_i+\beta)}{(T+\beta)\,(T_i-\beta)}\right]\right\} \qquad (8)$$

$$T' = \frac{T}{T_i},\ t' = T_i^3\,(t-t_1),\ \psi' = \frac{\psi}{T_i^4} \qquad (9)$$

Equation 8 has the particular advantage that the defined variables remain unchanged at each interval of time, but has the inherent disadvantage that many graphs or tables are required for adequate presentation of results.

On the other hand, the change of variable as defined by equation 9 allows for the compact presentation of results, but has the inherent disadvantage that each change of time interval will require a new set of parametric values. For this article, it is convenient to redefine the variables in order to minimize the number of graphs required for presentation. Thus, the results of equation 6, as typified by Fig. 2, may be employed directly to calculate temperature as outlined in the following:

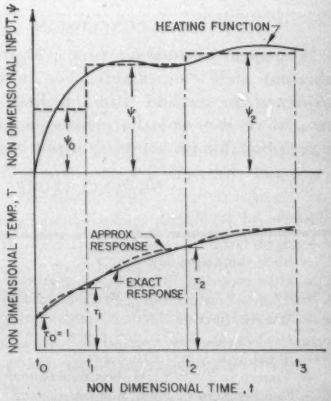


Fig. 4. Schematic representation of rectangular pulse approximation.

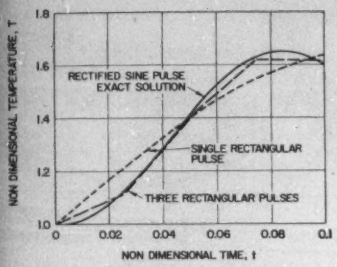
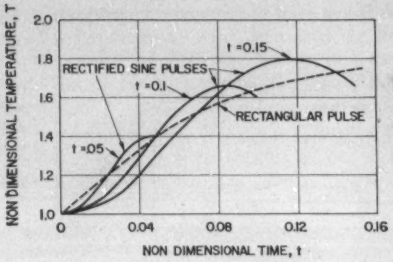


Fig. 5 (left). Rectangular pulse approximations of a rectified sine pulse. Fig. 6 (right). Similar approximations for different pulse durations.



1. Evaluate T, t, and $\beta = \psi^{\frac{1}{4}}$.
2. Approximate heating function by rectangular pulses as shown in Fig. 4.
3. In the initial interval, t_0 to t_1, T vs. t is found from Fig. 2.
4. In the second interval, evaluate $T' = T/T_1$, $t' = (t - t_1)\ T_1^3$, $\psi' = \psi/T_1^4 = (\beta/T_1)^4$, or $\beta = \beta'/T_1$.
5. Determine T' vs. t' from Fig. 2.
6. Convert T' and t' to T and t, respectively, for t from t_1 to t_2.
7. In the succeeding intervals, repeat steps 4 to 6 with T_1 replaced by the new initial conditions, T_i, $i = 2, 3$, etc.

Accuracy. The accuracy of the method increases with use of finer and finer intervals, but simultaneously, the computation becomes increasingly large. An indication of the proper size of the time interval is shown in Fig. 5. The exact time behavior of the system subjected to a rectified sine pulse is compared with two approximate solutions. The first approximate solution represents the response to single rectangular pulse approximation of the rectified sine pulse. The second approximate solution is the response of a more accurate (three rectangular pulses) approximation of the sine pulse. The increase in accuracy with smaller time intervals is quite noticeable. The height of the rectangular pulse was based on the equivalence of the total heat input to the system. That is, the area under the rectified sine pulse is equal to the area under the rectangular pulse.

It is interesting to note that the accuracy of the single rectangular pulse approximation of the sine pulse does not increase significantly with shorter time durations of the pulse. This is shown in Fig. 6.

CONCLUSION

A SIMPLE METHOD for predicting transient thin isothermal shell temperatures has been presented. The utility of the method is its simplicity and the compactness of results, and the method is quite general since it is applicable for arbitrary input heating functions.

NOMENCLATURE

Symbols

A = Area, feet^2
b = Shell thickness, feet
C_p = Heat capacity, Btu pounds^{-1} degrees F^{-1}
k = Thermal conductivity, Btu hours^{-1} feet^{-1} degrees F^{-1}
m = Weight, pounds
q = Heat input, Btu hours^{-1} feet^{-2}
Q = Total heat input, Btu hours^{-1}
t = Time ($\sigma \epsilon\ T_c^3/\gamma\ C_p\ b$), nondimensional
T = Temperature (T_1/T_0), nondimensional
x = Space variable, feet
y = Space variable, feet
γ = Weight density, pounds feet^{-3}
ψ = Parameter ($\psi = q/\sigma \epsilon\ T_0^4 = \beta^4$), nondimensional
θ = Angle, degrees
μ = Cos θ
ϵ = Emissivity, dimensionless
σ = Stefan-Boltzmann constant (0.1714×10^{-8}), Btu hours^{-1} feet^{-2} degrees R^{-4}

Subscripts

0 Initial
1 Dimensional quantity or first increment
2, 3 Second, third (etc.) in increments

Superscript

' Redefined variables

REFERENCES

1. The Temperature of an Orbiting Missile, A. R. Hibbs. *Progress Report no. 20-294*, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., Mar. 28, 1956.

2. Studies of a Minimum Orbital Unmanned Satellite of the Earth (MOUSE), D. T. Goldman, S. F. Singer, "Part III, Radiation Equilibrium and Temperature." Seventh International Astronautical Congress, Rome, Italy, Sept. 1956.

3. Satellite Temperature Control, L. F. Drummeter, Jr., M. Schach. *Progress Report*, U. S. Naval Research Laboratories, Washington, D. C., May 1958, pp. 1-7.

4. Temperature Stabilization of Highly Reflecting Spherical Satellites, M. Schach, G. Hass, L. F. Drummeter, Jr. *Journal*, Optical Society of America, New York, N. Y., vol. 49, no. 9, Sept. 1959.

5. Satellite Temperature Measurements for 1958, E. P. Buwalda, A. R. Hibbs. *External Publication no. 481*, Alpha-Explorer I, Jet Propulsion Laboratory, Apr. 1958.

6. Thermal Control of the Explorer Satellites, G. Heller. *Report no. DV-TN-17-59*, U. S. Army Ballistic Missile Agency, Washington, D. C., 1959.

7. Temperature Control in the Explorer Satellites and Pioneer Space Probes, E. P. Buwalda, A. R. Hibbs, T. O. Thostesen. *External Publication no. 647*, Jet Propulsion Laboratory, May 7, 1959.

8. Scientific Results from the Explorer Satellites and the Pioneer Space Probes, A. R. Hibbs. *External Publication no. 649*, Jet Propulsion Laboratory.

9. Space Vehicle Environment, C. Gazley, Jr., W. W. Kellogg, E. H. Vestine. *Journal of Aero/Space Sciences*, New York, N. Y., vol. 26, no. 12, 1959, pp. 770-71.

10. Preliminary Investigation of Hyperenvironments and Methods of Simulation, "Part I, Natural and Induced Environments Above 75,000 Feet," R. A. DiTaranto, J. J. Lamb. *WADC TR 57-456* (Armed Services Technical Information Agency Document no. AD-142000), Wright Air Development Center, Dayton, Ohio, July 1957, pp. 12-20.

11. Handbook of Geophysics for Air Force Designers (book), Geophysics Research Directorate, U. S. Airforce, Cambridge Research Center, Cambridge, Mass., 1957.

12. Temperature in Heated Finite Slabs with Fourth Power Loss, R. Greenstone. *Journal*, Washington Academy of Science, Washington, D. C., vol. 48, no. 11, Nov. 1958, pp. 341-46.

13. Unusual Techniques Employed in Heat Transfer Programs, D. J. Campbell, D. B. Vollendweider. "Proceedings of the 1959 Eastern Joint Computer Conference," AIEE *Special Publication T-114*.

14. Operational Methods in Nonlinear Mechanics, L. A. Pipes. *Report 51.10*, University of California at Los Angeles, Dec. 1951.

Electrical System Transients and Sensitive Circuit Control

T. B. OWEN
MEMBER AIEE

With the advent of solid-state devices and their susceptibility to destruction from transient impulses, there has been renewed interest in the subject of interference voltages. In this article, methods of controlling the coupling of transients into sensitive circuits are described.

AT ONE TIME a fairly extensive literature was compiled on the phenomenon then known as "radio noise".[1-3] At first this literature was almost exclusively concerned with what could be heard coming out of the headphones of a radio set that was not signal, and later on with "grass" that grew on the radar picture. There was an intense flurry of interest at the latter part of World War II, because of the general introduction of very-high-frequency equipment. However, once the problem had been brought down to its proper proportions and the interference eliminated, the whole question was dropped. Now, with the advent of solid-state devices and their susceptibility to destruction from transient impulses, and the increasing use of digital-type computers to which many transients look exactly like a "bit" of information, there has been a revival of interest in the subject. It is to be hoped that there will be at last enough continuing effort to obtain interference suppression by design, instead of last-minute frenzied efforts with a pocketful of filters and capacitors. Perhaps the current changes of name to "radio-frequency interference" or "electromagnetic interference" will help.[4-8]

In view of the fact that the information on the problem is not much greater now than it was in World War II, with a consequent lack of appreciation for the requisites for an engineering solution thereof, an outline of the problem will be set forth here in engineering terms. With this outline, each individual case can be examined on its own merits. Above all, it is the author's desire to take the problem out of the realm of the mysterious. Transients do not just happen; to cause trouble, they must be coupled to a "receiver" circuit. They do not flit mysteriously hither and yon with no visible means of support.

GENERAL CONSIDERATIONS

BEFORE PROCEEDING FURTHER, the main outlines of the problem must be set down. First, there must be a source creating an interference voltage; second, there must be a receiver circuit which would be affected by the interference voltage; and finally, coupling of some sort must exist between receiver and source. If any of the three elements is missing, interference will not result. For example, a motor may have violently sparking brushes creating a series of sharp transient pulses on the line, and there may be a very sensitive digital computer fed from the same line. However, if the coupling between the motor and the computer has been destroyed by filters, shielding, or any other means, interference will not result. All elements must be present; there can be no exception to this rule.

INTERFERENCE SOURCES

ROUGHLY SPEAKING, any piece of electric apparatus is a potential interference source. However, the interference-producing apparatus is not so important as the type of interference produced. Next in importance are the voltage–current–frequency relationships of the interference.

Transient Generation by Load or Regulation Change. In almost every case, transients generated by this method are characterized by fairly steep initial wavefronts, going back to a steady-state value at some later time, depending upon the regulation method, internal impedance, etc. The transients produced by this method are not more than 25%, except where the loads are at least 100% of full load, and the generator has a high impedance.

Transient Generation by Discharge of Storage Elements.

1. *Capacitive Discharges.* These are very infrequent. First a capacitive element must be charged to a voltage above the line to which it is to be connected, and then a connection must be made to the line, so that the stored energy will be discharged. The transient is characterized by a high peak voltage followed by an exponential decay to normal line voltage. It may be oscillatory, depending upon the circuit parameters.

2. *Inductive Discharges.* These are very common forms of transient generators. Motors, solenoids, relays, or the interruption of any inductive circuit will cause transients of this type. In the inductance L, a current I flows, resulting in the energy storage.

Full text of paper 60-1029, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee. Published in AIEE *Applications and Industry*, Nov., 1960, pp. 382-86.

T. B. Owen is with the Douglas Aircraft Company, Santa Monica, Calif.

$$J = \frac{1}{2} LI^2 \text{ joules} \quad (1)$$

When the circuit is opened, this energy must be discharged and/or dissipated. This may be accomplished by an arc at the switch contacts, or it may be transferred to the distributed capacitance of the inductor and its circuit up to and including the switch. The energy stored in the capacitance, the capacitance C, and the voltage E are related as follows:

$$J = \frac{1}{2} CE^2 \text{ joules} \quad (2)$$

Thus, if all the energy in the inductor is transferred to the capacitance, the maximum instantaneous voltage across the capacitance will be

$$E = \sqrt{\frac{L}{C}}\, I \text{ volts} \quad (3)$$

This may be an oscillatory discharge; if the resistance is R, the frequency f will be

$$f = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \text{ cps (cycles per second)} \quad (4)$$

Thus, depending upon the circuit constants, an oscillatory discharge may appear across the inductor–circuit-capacitance combination. A transient has been created, the energy, voltage, and frequency of which may be readily calculated from a knowledge of the circuit parameters. So far, however, it must be remembered that this transient exists only in the L, C, and R combination of the inductor and distributed capacitance up to the switch that opened the circuit in the first place.

3. *Transient Generation by Diode Switching.* The introduction of the high-efficiency silicon diode has brought about a whole new class of interference-producing devices. A relay or solenoid produces a transient only when it is switched; when diodes are introduced to make the d-c device operate as an a-c device, transients occur at or near zero voltage points of the cycle. Here, the diode changes abruptly from a closed circuit to an open circuit. Unless this switching takes place at exactly current zero, some stored energy remains in the solenoid or relay and must be discharged. It has been shown[9] that there is a large reverse-current spike flowing through the diode at this time, producing an interference pulse. On 400-cps circuits where half-wave rectification is used, the interference will be 400 pulses per second. For full-wave rectification, it will be 800 pulses per second. The reason that this interference has arisen with the introduction of the silicon diode is twofold: first, the diode was introduced at the same time that a-c systems on aircraft became popular, so that the applications for diodes as rectifiers multiplied; second, this diode is a much more efficient switch than others previously used. Germanium and similar diodes also produce switching pulses, but of much less intensity than the silicon.

Lamp Load Switching Transients. The "cold" resistance of the ordinary incandescent lamp is approximately 1/10 the "hot" resistance. Therefore, lamp circuits, when switched to provide displays of one kind or another, must be carefully treated. Any lamp will have a steep-fronted current input, and a large-filament lamp, heating relatively slowly, will have an input current of 8 to 10 times the steady-state current. Such sharp wavefronts are capable of producing interference far beyond that which one would normally expect, and must always be treated with caution.

RECEIVER CIRCUITS

THE RECEIVER may generally be anything which is capable of a misoperation (not necessarily a malfunction) by the introduction of an unwanted signal. It may be an ordinary sensitive relay, or it may be some sort of amplifier-actuated device, such as a transistor or vacuum-tube amplifier, integrating and/or storing input signals. In any event, receivers may be put into two general classes: high input impedance and low input impedance. Generally, the main difference between these classes is the energy required to actuate them. For example, if the input impedances of two amplifiers are 1,000 and 100,000 ohms, respectively, and a 500-volt pulse lasting for 1 millisecond is required to actuate each of them, the watt-seconds of energy in both cases will be

$$J = \frac{500^2}{1{,}000}\, 10^{-3} = 0.25 \text{ watt-second for the 1,000-ohm input}$$

$$J = \frac{500^2}{100{,}000}\, 10^{-3} = 0.0025 \text{ watt-second for the 100,000-ohm input}$$

This is equivalent to saying that the high-impedance receiver is more "sensitive" than the low-impedance device. Transients with 0.25 watt-second of energy are quite rare, those of 0.0025 watt-second may be more numerous, for this is equivalent to the discharge of an inductor of 0.1 henry with a current flow of 0.7 ampere. It is very clear that one method of desensitizing a receiver circuit is to change it from high- to low-impedance input. Essentially, this is what is done when an input filter is installed. The receiver may look into a high-impedance load, but to the rest of the circuit, the receiver may look like a very low impedance. This must not be done indiscriminately, since one undesirable effect may be to convert a high-impedance line with a high voltage pulse on it to a low-impedance line with a high current pulse on it. In coupling to other circuits, the high current pulse is much more effective, as will be seen later. It must suffice to say here that while low-impedance devices are very desirable at transient frequencies, great care must be exercised to insure that the conversion to low impedance does not bring up other troubles.

COUPLING CIRCUITS

CIRCUIT COUPLING is much misunderstood. Although it is quite common to speak of a solenoid, relay, or other

device radiating energy to receivers, this is only very exceptionally the case. Thus, some time will be taken to show how this phenomenon comes about. It is very important that correct terminology be used.

Radiation Coupling. In reference 10, the following is given as the field strength in electromagnetic units, at a distance of r centimeters from and normal to a dipole of length l centimeters, and a current of I amperes flowing in the dipole:

$$h = lI\left[\frac{\omega}{rc}\sin\left(\omega t - \frac{r\omega}{c}\right) - \frac{\cos\left(\omega t - \frac{r\omega}{c}\right)}{r^2}\right] \quad (5)$$

From an examination of this equation, the following is evident:

1. The first term varies inversely with distance, the second inversely as the square of the distance.

2. The first term is smaller than the second in the ratio ω/c at zero distance. Numerically, they become equal at $r = c/\omega$; at 1 mc, this is 478 meters. At lesser distances, the second term predominates.

3. As ω approaches zero, or the d-c condition, the first term vanishes, and the second term only is left. It is now identical with the familiar equation for d-c magnetic induction.

4. As a consequence, at the distances commonly involved in aircraft and missiles, a few meters at most, the radiation field (the first term) is very small and is not effective in producing an interference field; the induction field (the second term) decreases rapidly with distance but is the actual interference field, if one is effective. At all except the kilomegacycle range and above, the radiation field may be neglected for all practical purposes.

Induction Field Coupling. From what has been shown in the preceding section on radiation coupling, any field set up by current flow can be calculated from ordinary induction field theory. Then, if the length of wire composing the receiver circuit that is subjected to a certain field is known, the total field may be found, and the voltage induced in the receiver wire found by a knowledge of the rate of change of flux in the field.

$$E = -N\frac{d\phi}{dt} \text{ volts} \quad (6)$$

This is the *only* method by which induction coupling may exist, e.g. (1) an induction field is set up by a current flow, (2) a receiver wire is in this field, (3) the induction field is changing as a function of time. An unchanging field, as one set up by a direct current, will not couple into an adjacent circuit, but the ripple, hash, or transients on the d-c line may be coupled, since they represent a field-flux change.

1. *Induction Field Extent.* A current flow in a wire implies a return flow, and the induction field thus is thought of as a field between two conductors. Now, the inductance of such a loop of wire depends directly upon the distance between the two wires and their diameter. The total impedance

$$Z = R_{dc} + j\left(0.0529\frac{f}{60}\log_{10}\frac{2s}{d} + X_i\right) \text{ ohms per 1,000 feet} \quad (7)$$

where

f = frequency in cps

s = distance between the two wires

d = wire diameter

X_i = internal reactance

Thus, except in the case of direct current, spacing the wires close together decreases the circuit impedance. Obviously, it also reduces the extent of the field, although theoretically the field extends out to infinity. Let us examine this concept. If we assume two conductors, going and return, the impedance of a field element directly between the two will be less than for field element with a path twice as long. Thus, a field set up by an alternating current will tend to concentrate in as small an area as possible between the two conductors. Where there is a single conductor with return through a flat ground plane, as in aircraft or missile structure, the field will concentrate in a small area between the wire and the structure, with return current in the structure confined to a small area directly opposite the wire. The higher the frequency, the more confined the field will be, and with very close spacings where wiring is laid directly on the ground plane, or where twisted pairs are used, the field may be quite small.

2. *Induction Field Shielding.* The permeability of copper is the same as that of air or vacuum, so that copper braid shield has no effect on a field other than the voltage induced in it as a function of field change. The only material which is effective as an induction shield at low frequencies is a ferromagnetic material, which offers a lower reluctance path than air or vacuum. At high frequencies, a solid copper shield is effective if correctly installed. The installation of shield braid to cut down induction field coupling is usually a waste of material; however, it is effective as an electric field shield. Thus, military specifications require that power cables not be shielded, because shielding gives a false sense of security.

3. *Induction Field Control.* Where power cables are used, the induction field may be minimized, not eliminated, by making the current return path as close as possible, or possibly running twisted pairs as an extreme measure. Further, power cables should never be run in bundles with other wiring. Since the field decreases inversely as the square of the distance, a small separation will decrease coupling by decreasing the interference field.

Electric Field Coupling. Coupling may occur as a result of the capacitance between two objects. If a voltage appears on one of two objects, a voltage will also appear on the other by virtue of capacitive coupling. Current

is not involved, all that is necessary is that one object be charged and that there be capacitive coupling to the other. Shielding here is very simple, and may consist of placing the two objects so that there is no capacitance between them, or alternatively, interposing a metallic shield between them which is at ground potential, so that there is capacitance between both objects and ground but not between the objects.

It is unfortunate that the difference between electrostatic and electromagnetic shielding is often misunderstood. One finds that electrostatic shielding is frequently applied in the mistaken notion that it will also serve as an electromagnetic shield. It is probably these instances which have given rise to the idea that shielding is ineffective or, in a given case, does not work at all. Electrostatic shielding is very easily applied and understood, and is entirely effective if the coupling is capacitive. It is purely fortuitous when electrostatic shielding entirely cures a case of interference couping, because in most cases the coupling path is through both the electric and the magnetic fields.

INTERFERENCE CONTROL

To RECAPITULATE what was stated under "General Considerations," in order to have interference of any kind, all three of the following must be present:

1. A source must be actively generating interference voltages and currents.
2. A receiver circuit which may be affected by the interference voltages or currents must be present.
3. A coupling means must be present between the source and the receiver.

If any one of these elements is missing, regardless of the presence or intensity of the others, interference will not result. Clearly, then, interference may be eliminated by controlling any one of the three elements. Unfortunately, in the past more attention has been paid to source suppression than to other methods, probably because the device itself is so readily identifiable as an interference source. The result very often has been to leave the designer of the receiver virtually a free hand; no restrictions are placed on his activities. The result is obvious: the airframe manufacturer is required to install an article to which the designer has attached a list of almost impossible demands in the way of voltage, frequency, and transient tolerances. Meeting these demands has involved greatly increased costs in vehicle weight and performance, which in most instances would have been avoided if the equipment designer had thought of his article as a part of a system, not as an isolated unit.

Interference Control by Source Suppression. Many cases where this is the most practical method immediately come to mind; e.g., a motor may have sparking brushes or the contact on a relay or switch may spark violently. In such cases there is no doubt as to the remedy, since suppression of the interference also improves the operation of the circuit or device. The case is not so clear in other areas.

1. *Relay or Solenoid Slugging.* If interference is caused by the discharge of the stored energy of an inductor, it may be eliminated by providing a low-impedance path in which the energy may be dissipated. Such is often done by providing by-pass diodes, etc. However, this is not always clear gain, for a relay or solenoid may be "slugged," or its time of operation changed, by the application of diodes. In some cases, this may delay the relay drop-outs to a half second or so, giving rise to uncoordinated circuit operation. Slugging, either by diodes, resistors, or capacitors, may certainly be used to suppress a source transient, but the effect upon the operation of the component in the system must also be taken into account.

2. *Source Filtering.* This is a very popular method of source suppression, and may be very effective, especially on small motors. Commonly, a π-type filter is used, capacitor–inductor–capacitor, so that the motor looks into a low impedance, and the impedance looking toward the motor is also low. This will have two effects, which must be taken into account:

a. The interference generator in the motor may be considered as one operating at many frequencies, with resonant and antiresonant internal impedances. That is, at some frequencies it is a voltage generator and at others it is a current generator. The effect of terminating such a generator in a low-impedance capacitor is to make the interference currents high at all frequencies. The capacitor must be physically located directly on the device, so that the interference currents do not flow outside it. Further, it is essential that the high r-f currents inside the device be confined there. All openings, etc., must be carefully shielded by construction or by placing a heavy copper screen over them. In any event, the r-f interference currents and the heavy associated field must be contained within the device. If the currents flow outside at any point, a field is set up which may couple to adjacent wiring.

b. The filter looks like a low impedance to the rest of the circuit, and may cause the flow of heavy transient currents instead of the transients appearing as voltages on the line. Many cases of interference have been "cleared" in this manner. The interference voltage disappears but the interference is still present, possibly in another receiver previously unaffected.

Interference Control by Receiver Design. This is a most controversial area, and no hard-and-fast rules can be set down. However, it is certainly the responsibility of the designer to make his equipment as inherently good as he can. That is to say, the design should not be such as to increase unnecessarily the susceptibility to coupling to an adjacent field. Inputs should be isolated as much as possible, and certainly there should be no coupling between input and output.

As a rough criterion, it would seem that a device

should be at least one order more sensitive to signals on a designated input terminal than to signals of the same frequency upon power supply, control, or output wiring. This might not seem to be much of a requirement, but the author has had experiences with equipment more sensitive to signals on the power supply than to signals on the input. It is certainly no reflection upon the man installing such equipment that he has interference troubles, although this is generally where the blame falls.

There is no point in taking this facet of the problem any further. The equipment designer should certainly know the part his design will play in the system, and not make severe demands upon others merely because it lightens his burden.

Interference Control by Coupling Control

1. *Induction and Electric Field Coupling.* There is nothing quite so effective as physically separating the receiver from the source, inasmuch as the induction field decreases as the square of the distance and the electric field directly as the distance. The applicable methods here may be summarized briefly as follows:

a. Provide physical separation between the two circuits.

b. Provide electrostatic shielding by design if possible; i.e., run sensitive circuits close to the ground plane, with metal between them and source circuits.

c. Minimize the field area of both receiver and source by running the circuit wire and its return path as close together as possible. This may mean a twisted pair or a wire close to the ground plane.

d. If a receiver wire must be exposed to a field, provide for cancellation effects by running it as a twisted pair with proper treatment at the receiver end so that the two induced voltages cancel.

2. *Source Wiring Impedance Control.* If such wiring is made low impedance by the installation of capacitors, bleed resistors, batteries, etc., high interference voltages cannot occur on account of the energy requirements. However, such devices may convert a high-voltage transient to a high-current one and unexpected coupling occurs, due to induction fields. Properly used, these are excellent devices, and their usages may be summarized as follows:

a. Install capacitors, resistances, batteries, so that the induction field set up by high interference currents do not couple into wiring farther downstream.

b. A storage battery has an effective capacitance of 17,000 microfarads per ampere-hour,[11] at least in the smaller sizes. It is much better than a capacitor for making a line low impedance on d-c circuits.

c. A capacitor must be the noninductively wound type. This is a special type, and must be so specified and purchased. Electrolytics, tantalytics, and metallized capacitors are generally unsuitable for this service. Only the highest quality oil-filled capacitors should be used. A further restriction is that where capacitors are used on a-c lines, only certain types are suitable. These types of capacitors are so designated in the manufacturers' literature.

CONCLUSION

THE FOREGOING was not intended to introduce anything new or original. Certainly, there is little of this in most engineering fields. The intent has been to set forth well-known, tested, tried-and-true methods of controlling the coupling of transients into sensitive circuits. All of the methods set forth are well known to those who have been chasing "radio noise" for many years. It is the devices affected by interference voltages and currents that have changed; the principles are the same as those used over 15 years ago. To summarize,

1. For interference to be a problem, there must be a source, a receiver, and a coupling means.

2. Methods of reducing or eliminating the interference produced by most devices are well known, and when applied within their limitations are successful.

3. Design of the receiver for decreased sensitivity to interference signals on other than its input is a fundamental responsibility of the equipment designer.

4. Interference fields may be reduced in intensity and volume by control of the wiring to the device producing the interference.

5. Coupling between an interference field and a sensitive circuit may be decreased by control of source and receiver wiring to the point that it is not significant.

6. Interference field control may be obtained by decreasing the impedance of the lines carrying the interference signals. Unless care is used, this may decrease interference voltages at the expense of interference currents.

7. No one method of control is to be preferred above all others. Judicious use of the various control devices is preferred. Nevertheless, in original design it is well to exercise control over all areas if possible, so that an interference-free installation will result.

REFERENCES

1. Radio-Noise Elimination in All-Metal Aircraft, Fred Foulon. AIEE *Transactions*, vol. 62, 1943, pp. 877-91.

2. Very High-Frequency Radio-Noise Elimination, T. B. Owen. *Ibid.*, vol. 63, 1944, pp. 949-54.

3. Tracking Radio Noise on Aircraft, T. B. Owen, *Ibid.*, vol. 69, pt. II, 1950, pp. 1249-52.

4. RFI—An Up-To-Date Survey, R. B. Schultz, H. M. Sacks, G. C. Vallender. *Electronic Design*, New York, N. Y., Feb. 3, 1960, pp. 26-37.

5. RFI—Check List, L. W. Thomas. *Ibid.*, pp. 38-43.

6. RFI—Interference Trouble-Shooting with Clamp-On Devices, T. H. Herring. *Ibid.*, pp. 44-47.

7. RFI—Optimum Shielding of Equipment Enclosures, A. L. Albin. *Ibid.*, pp. 48-49.

8. Aircraft and Missile Electric Systems Guide. AIEE *no. 750*, sect. 400, par. 454.

9. Radio Interference Control of Semiconductor Circuitry, F. J. Nichols. *Proceedings*, Fourth Conference on Radio Interference Reduction and Electronic Compatibility, Armour Research Foundation, Illinois Institute of Technology, Chicago, Ill., vol. 4, Oct. 1958, pp. 487-510.

10. Reference Data for Radio Engineers. Federal Telephone and Radio Corporation, Clifton, N. J., fourth edition.

11. Battery Impedance—Farads, Milliohms, Microhenries, AIEE *Transactions*, E. Willihnganz, Peter Rohner. AIEE *Transactions*, pt. II *(Applications and Industry)*, vol. 78, Sept. 1959, pp. 259-62; *Electrical Engineering*, vol. 78, Sept. 1959, pp. 922-25.

One-Point Ground System with R-F Shielding and Filtering

R. A. VARONE

An organized plan for handling the problem of grounding, shielding, and filtering the electronic system for missiles and ground support equipment is presented. The result is a one-point ground for the complete system, with all ground loops open.

THE PRESENT-DAY MISSILE is a very complex vehicle which has become extensively dependent on electronics for the performance of its flight mission. Navigational guidance, communication, launching, and prelaunch checking have become the responsibility of electronic equipment integrated into a system. Just as the missile is a complex device, the electronic equipment has also become more complex; and integration of the electronic subsystems and electronic packages to constitute a system has presented many problems in the areas of grounding, shielding, and filtering.

The complexity of the electronic system has made obsolete the old rule-of-thumb methods of grounding, shielding, and filtering. An organized plan of handling this area of design on a system basis is presented. Radio-frequency interference (RFI), which progressively has become a major problem, is also treated. The approach is to design for the elimination or reduction of RFI in the initial design stages, rather than wait until the first article is ready for test and introduce fixes which are never cures.

Grounding the missile and electronic system has been approached from the point of view that ground circuits are uniquely known and controllable. The result is a one-point ground for the complete system. All loops in the ground circuit are open, so that under normal operating conditions no current flows in the ground leads. As a result, when the missile is broken away from the pad at launch, sparking, flashing, and other phenomena resulting from breaking a current-carrying circuit have been eliminated.

THE ONE-POINT GROUND

THE ONE-POINT GROUND, as applied to a weapon system consisting of missile and ground support equipment, is illustrated in Fig. 1. The philosophy has been extended to a weapon system employing more than one missile, as illustrated in Fig. 2. The following constitute the salient aspects of the design philosophy:

1. One-point ground for the complete system.
2. Common approach for all designs.
3. All metal surfaces which can be contacted by the human body at earth potential.
4. All ground loops open; therefore, no direct current or low-frequency alternating current in ground leads.
5. All ground support equipment power supplies grounded at source end only.
6. All shields tied to one-point ground.
   a. To missile, if signal originates in missile.
   b. To ground support equipment, if signal originates in ground support equipment.

System Static Grounding. The purpose of static grounding is to place all equipment and metallic surfaces that can be contacted by the human body at earth potential.

In Fig. 1, it has been assumed that the ground support equipment—the power supply area and two ground support equipment areas—are separated by several hundred feet in order to keep the solution general. Therefore, the static ground of each area is returned to earth ground at the launch ring or ground grid by a separate lead namely; by leads 1, 3, and 4. It should be noted that all chassis are tied to structure ground and that all ground loops are open.

The missile is tied to earth ground at the ground longeron, as illustrated in Fig. 1. The missile launcher or structure is also tied to earth ground.

In many installations, the ground support equipment is cohesively packaged, as illustrated in the upper left-hand corner of Fig. 1. In this case, the consoles or racks are tied with a heavy ground strap and bonded. The inductance of the ground straps must be very low. As a result of cohesive packaging, leads 1 and 4 are replaced by a single lead, 3.

Missile and Ground Support Power Grounding. Some missiles employ a 3-terminal motor–generator for engine starting and battery charging. In order to start the engine, a separate 28-volt power supply must be provided by the ground support equipment, as shown in Fig. 3.

The power circuit is closed, with the return current carried in lead 7. This power supply is grounded to earth ground at the missile longeron, which is at the load end of the power source. By treating it in this way,

Condensed text of conference paper CP60-1067, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

R. A. Varone is with The Martin Company, Baltimore, Md.

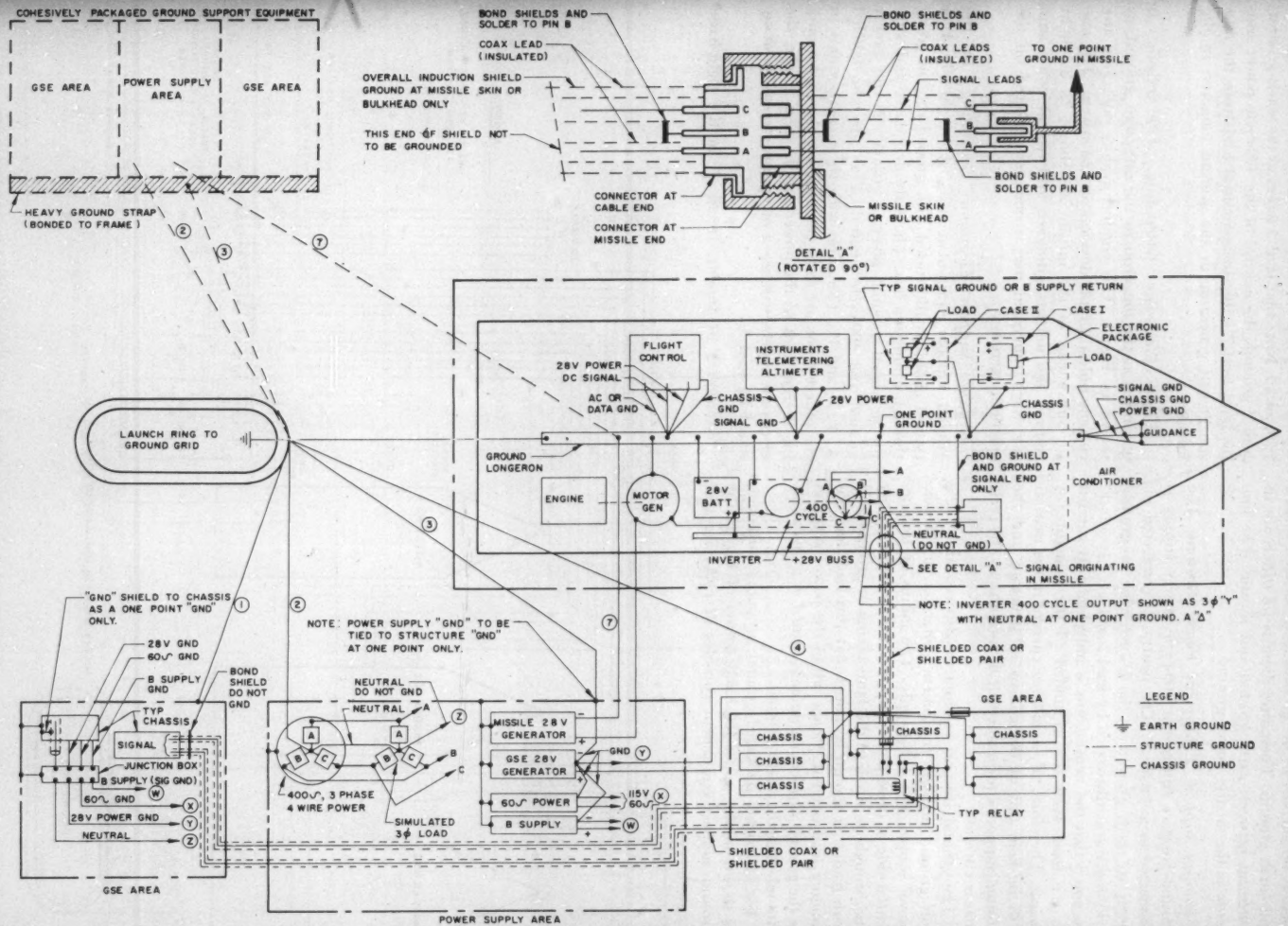


Fig. 1. Functional system schematic diagram of missile and ground support equipment grounding.

there is no current in the ground lead between missile and earth ground. Therefore, there is no difference in potential between earth ground and missile. The longeron is the missile power ground.

Ground Support Equipment Power Ground. The ground support equipment 400-cycle power supply is connected as a 4-wire Y. The neutral is connected directly to earth ground at the launch ring or ground grid and this is illustrated by lead 2 of Fig. 3. It should be noted that the neutral bus is independently carried to the load. It is not grounded to the structure or chassis. Therefore, any unbalance current in the neutral will be kept out of the chassis or structure and the ground support equipment will be immune to 400-cycle chassis currents.

The ground support equipment also contains a 28-volt ground support equipment generator, a 60-cycle power source, and a *B* supply. The minus or low potential side of these power supplies are all tied together and brought to earth at the launch ring or ground grid with lead 3. It should be noted that this lead does not conduct load current. Hence, all of the power supplies in the ground support equipment return to a one-point ground—namely, earth ground.

For cohesively packaged ground support equipment, as shown in the upper left-hand corner of Fig. 3, the ground support equipment consoles or racks are tied with a heavy ground strap and ground-connecting lead 2, 3, and 7. Note that lead 3 serves as the static ground, lead 2 grounds the neutral of the 400-cycle power supply, and lead 7 is the low-potential lead from the missile 28-volt generator to the ground longeron in the missile.

Missile Electronic Grounding. The missile is grounded at the longeron to the one-point ground, as shown in Fig. 1. This conductor does not carry any current unless a fault develops in the system. The major subsystems of the missile are shown to be flight control, instruments, guidance, and typical power supply. Each subsystem uses a one-point ground on the missile longeron.

Ground Support Electronic Grounding. In the ground support equipment areas, shown in Fig. 1, a typical chassis is illustrated with ground returns going through a junction box. These are designated as *B* supply or signal ground, 60-cycle ground, 28-volt power ground and 400-cycle neutral. They are also labeled *X*, *Y*, *Z*, and *W*. The wires with these designations in the junction box are to be connected to the corresponding designations in the power supply area. Hence, the electronic system will see a one-point ground as designated by lead 3.

Grounding of Shields. Detail *A*, in the right-hand

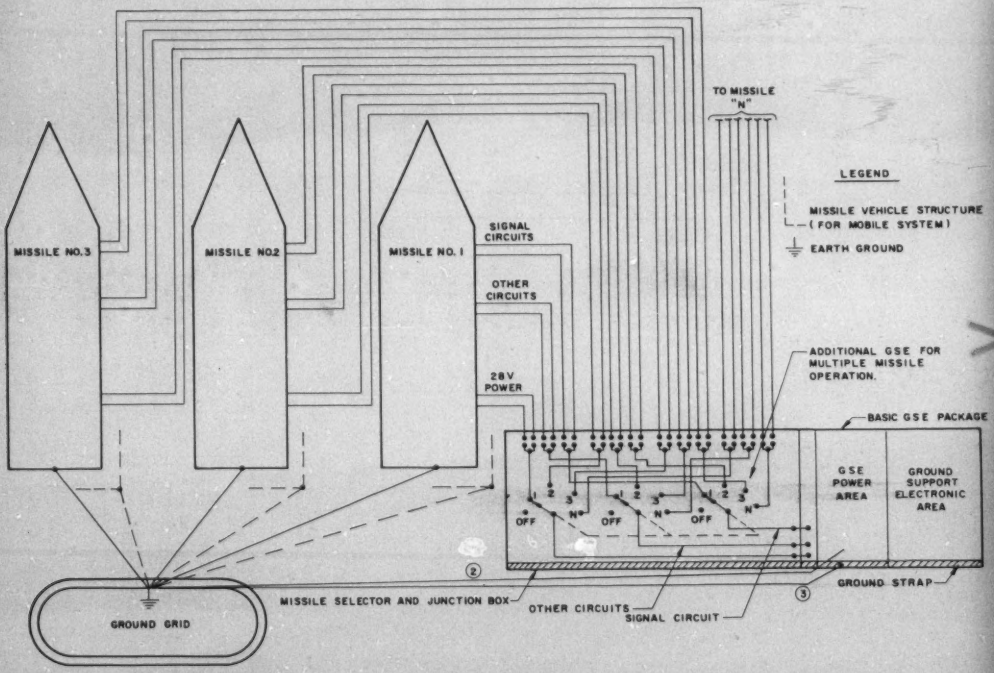


Fig. 2. Functional system schematic diagram of multiple missile and ground support equipment grounding.

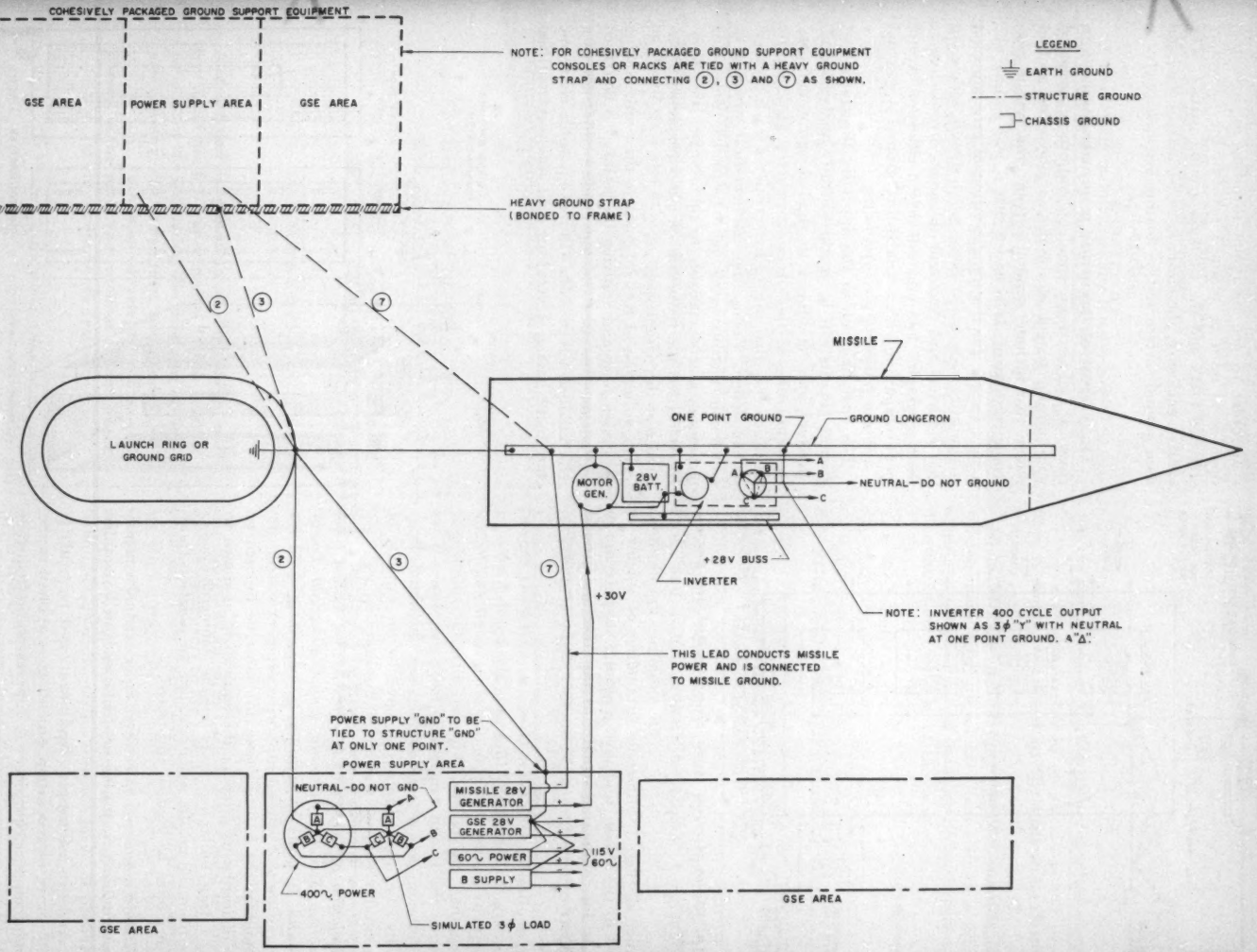

COHESIVELY PACKAGED GROUND SUPPORT EQUIPMENT
GSE AREA
POWER SUPPLY AREA
GSE AREA
NOTE: FOR COHESIVELY PACKAGED GROUND SUPPORT EQUIPMENT CONSOLES OR RACKS ARE TIED WITH A HEAVY GROUND STRAP AND CONNECTING (2), (3) AND (7) AS SHOWN.
LEGEND
EARTH GROUND
STRUCTURE GROUND
CHASSIS GROUND
HEAVY GROUND STRAP (BONDED TO FRAME)
MISSILE
LAUNCH RING OR GROUND GRID
ONE POINT GROUND
GROUND LONGERON
MOTOR GEN.
28V BATT.
NEUTRAL—DO NOT GROUND
+28V BUSS
INVERTER
+30V
NOTE: INVERTER 400 CYCLE OUTPUT SHOWN AS 3φ "Y" WITH NEUTRAL AT ONE POINT GROUND. A "Δ".
THIS LEAD CONDUCTS MISSILE POWER AND IS CONNECTED TO MISSILE GROUND.
POWER SUPPLY "GND" TO BE TIED TO STRUCTURE "GND" AT ONLY ONE POINT.
POWER SUPPLY AREA
NEUTRAL-DO NOT GND
MISSILE 28V GENERATOR
GSE 28V GENERATOR
60~ POWER
B SUPPLY
115V 60~
400~ POWER
SIMULATED 3φ LOAD
GSE AREA
GSE AREA

Fig. 3. Missile and ground support equipment power grounding.

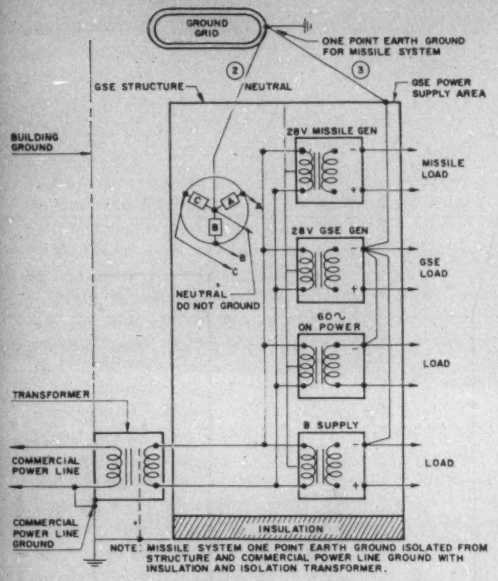


Fig. 4. Isolation of missile system one-point ground from structural ground.

corner of Fig. 1, illustrates grounding of shields as used in the missile and in the ground support equipment, for conducting signal currents from one ground support equipment area to another equipment area.

Extension of One-Point Ground to Multiple Operation. Fig. 2 functionally illustrates the application of a one-point ground system to a weapon system employing more than one missile. Theoretically, the number of missiles the system can handle has a range of one, as a minimum, and a large number as a maximum. Practically, the upper limit is dictated by the capacity of present-day switches and circuit applications.

Isolation of One-Point Missile Ground System from Building Structure Ground and Commercial Power Ground. In order to maintain a one-point ground for the missile and ground support equipment system, the ground in the building structure must be isolated by use of insulating pliers or the equivalent, as shown in Fig. 4. In a similar way, to isolate the commercial power line from the missile system ground, an isolation transformer must be used, as illustrated.

Radio-Frequency Shielding. Since radio-frequency power radiates, screening or shielding must be applied to reduce the field intensity in the vicinity of the missile and ground support equipment, and particularly at its source of generation. Shielding, as applied to the ground support equipment to suppress radio-frequency radiation, is accomplished by making each rack a self-contained screen room. The conversion of the individual rack to a screen room is illustrated in Fig. 5.

In order to get maximum shielding or screening, open loops must be retained between the individual screened racks and the common ground surface. The cabinet enclosure, therefore, must be tied to the common ground surface and be floating everywhere else

CONCLUSIONS

THE PURPOSE of this article is to make available to electrical and electronic engineers and others associated with missile system electronics, a one-point ground system that includes ground support and missile electronic equipment. It is hoped that it will become the basic reference for the standarization of grounding on an industry-wide basis. Basic rules should follow, so that electrical and electronic designers, irrespective of their geographic location, will design electronic equipment compatible with a standardized ground system and a uniform philosophy of grounding.

The analysis given in the appendix illustrates that ground circuits can be mathematically analyzed and, therefore, can be subject to rigid design techniques. Determination of the circuit parameters may require measurements that are characteristic of each weapon system design. Combining mathematical analysis of multimesh circuits with radio-frequency measuring techniques makes available to the designer the necessary tools for the reduction of radio frequency interference at the design stage.

The reduction of RFI by going to the source during the design stage and applying the techniques described will advance the art. The conversion of the rack to a self-contained screen room will make possible electronic equipment having a very low field intensity resulting

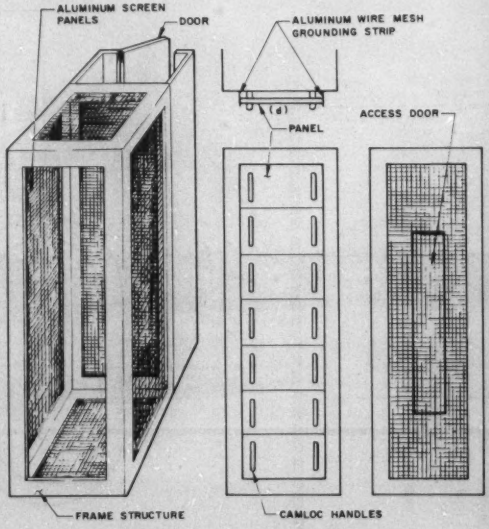


Fig. 5. Unitized rack-type screen structure.

from radiation. Judicious application of filtering will make electronic equipment less sensitive to pulses or spikes appearing on the power bus, and thereby improve reliability and performance.

Appendix

To minimize radio-frequency interference, it is necessary to analyze the ground loops which are open to direct current but closed to radio frequency. The power circuit of Fig. 2 can be represented in simplified form by Fig. 6 at rated frequency.

E_1 can be an r-f component of voltage during engine start. Solving equations 1 and 2 for I_1 and I_2, the mesh equations are

$$E_1 = I_1 Z_{11} + I_2 Z_{12} \tag{1}$$

$$0 = I_1 Z_{12} + I_2 Z_{22} \tag{2}$$

$$I_1 = \frac{E_1 Z_{22}}{Z_{11} Z_{22} - Z_{12}^2} \tag{3}$$

$$I_2 = \frac{-E_1 Z_{12}}{Z_{11} Z_{22} - Z_{12}^2} \tag{4}$$

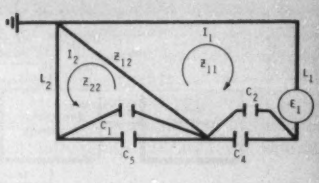
To keep radiation to a minimum, I_1 and I_2 should be as small as possible.

Each mesh has a self-resonant frequency, represented by equations 5 and 6:

$$f_{11} \doteq \frac{1}{2\pi\sqrt{L_1(C_2 + C_4)}} \tag{5}$$

$$f_{22} \doteq \frac{1}{2\pi\sqrt{L_2(C_1 + C_5)}} \tag{6}$$

Fig. 6. Power circuit of Fig. 3 in simplified form.



If the parameters of Z_{11} and Z_{22} are so adjusted that f_{11} and f_{22} are far removed from the frequency of I_1, then I_1 and I_2 will be relatively small and radiation reduced.

In many cases the network is more complex, involving more than two meshes; then a set of p simultaneous equations must be used for a p mesh network. The equations would be of the form

$$E_1 = Z_{11}I_1 + Z_{12}I_2 + Z_{13}I_3 + \ldots + Z_{1p}I_p$$
$$E_2 = Z_{21}I_1 + Z_{22}I_2 + Z_{23}I_3 + \ldots + Z_{2p}I_p$$
$$E_3 = Z_{31}I_1 + Z_{32}I_2 + Z_{33}I_3 + \ldots + Z_{3p}I_p$$
$$E_p = Z_{p1}I_1 + Z_{p2}I_2 + Z_{p3}I_3 + \ldots + Z_{pp}I_p$$

The unknowns are I_1, I_2, $I_3 \ldots I_p$, the impedances Z are to be computed or measured, and the transfer impedance E_1/I_p should always be large.

Since the spectrum of frequencies encountered is wide, it may be necessary to use low frequency, VHF, UHF, and even microwave techniques to accomplish conditions of minimum RFI.

REFERENCES

1. Communication Engineering (book), W. L. Everitt, G. E. Anner. McGraw-Hill Book Company, Inc., New York, N. Y., 1956.

2. High Frequency Alternating Currents (book), Knox McIlwain, J. G. Brainerd. John Wiley & Sons, Inc., New York, N. Y., 1939.

Evolution and Testing of a Navigational Satellite

M. A. SCHREIBER
MEMBER AIEE

T. WYATT

A discussion is presented of the design and testing of the first experimental Transit satellite developed for measuring the precision of Doppler tracking, navigation tests, and geodetic determinations. Techniques developed will be employed in the prototype satellites for use in the Transit navigational system.

PROJECT Transit is the code name of a program aimed at achieving a passive, world-wide, all-weather navigating system. The system is based on the fact that an analysis of the doppler shift in signals transmitted by an earth satellite can be used to obtain orbital parameters of the satellite with a high degree of precision. Then, conversely, if the orbital parameters are known precisely, the observer's location can be determined accurately. Conceived at the Applied Physics Laboratory in 1958[1], the program, originally sponsored by the Advanced Research Projects Agency, Department of Defense, is now completely under the direction of

Abridged text of paper, CP 60-1038, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

M. A. Schreiber and T. Wyatt are with the Applied Physics Laboratories of The Johns Hopkins University, Silver Spring, Md.

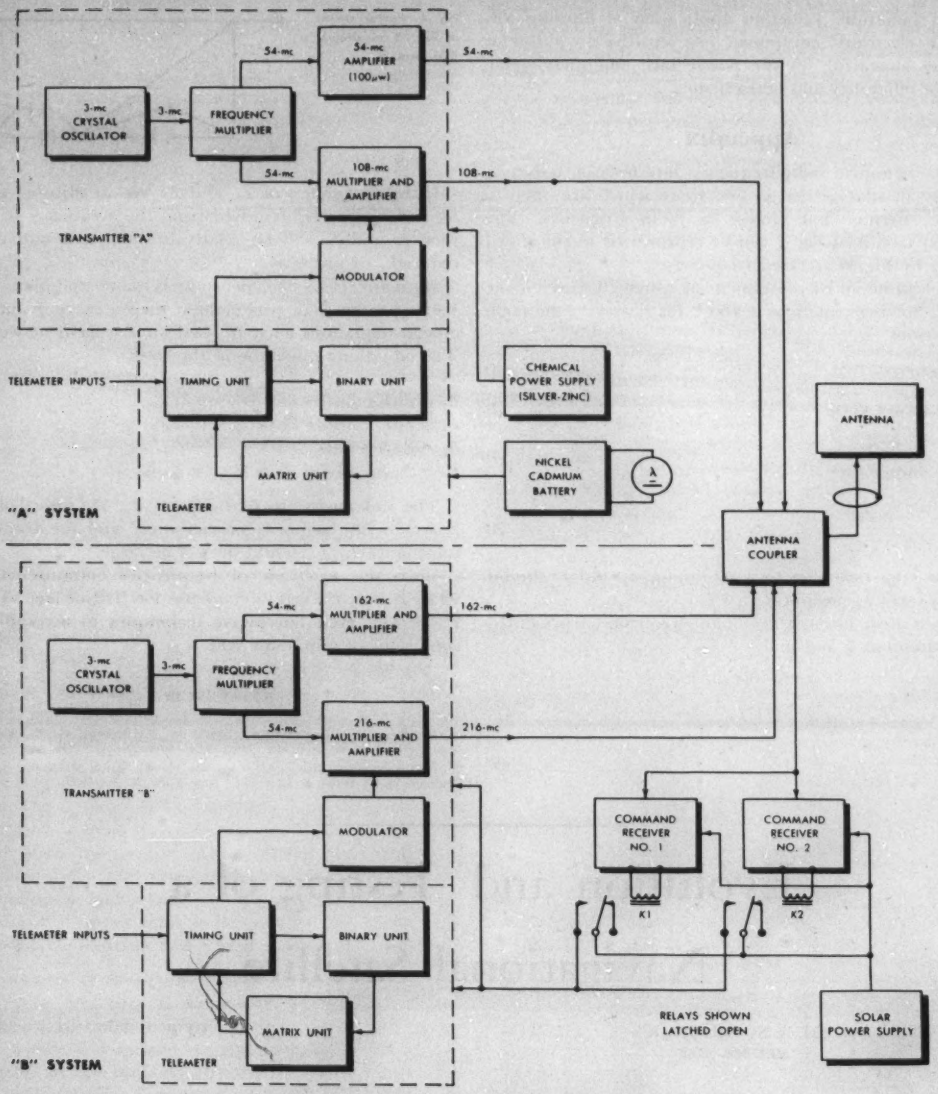


Fig. 1. Block diagram of Transit 1A electronics system.

the Bureau of Naval Weapons, Department of the Navy.

While a detailed description of the navigational system is beyond the scope of this article and has been presented elsewhere,[2,3,4] the greatly simplified description of the basic computational procedure presented herein may be helpful.

The Doppler shift in r-f signals transmitted from an earth satellite is a direct measure of the rate of change with respect to time of the distance between the receiver and the transmitter. In a vacuum, this shift Δf may be expressed as

$$\Delta f = \frac{-F_t}{c}\frac{dS}{dt}$$

where F_t is the satellite transmitter frequency, c is the velocity of light, S is the slant range from user to satel-

lite, and t is time. Upon measuring Δf, dS/dt can be computed for time t. After selecting an appropriate coordinate system, dS/dt can be expressed in terms of the satellite and user positions. For different time samples during one pass of the satellite, simultaneous equations can be written from the integrated expression for dS/dt; these equations may then be solved for the position of the user.

STATUS OF EXPERIMENT

THE FIRST EXPERIMENTAL navigational satellite that was constructed and tested was designated Transit *1A*. It was launched on September 17, 1959, by a Thor-Able vehicle at Cape Canaveral Military Test Annex.

Transit *1A* reached the orbital altitude, but, owing to the failure of the third-stage engine of the launching vehicle to ignite, it did not acquire orbital velocity, and hence did not go into orbit.

The second launching attempt, made on April 13, 1960, employed Transit *1B* which is functionally similar to the first model. It was successfully injected into orbit by a Thor-Able Star vehicle and has operated completely satisfactorily as of May 15, 1960, and adequately demonstrated the achievement of all objectives.

Although all the experimental test objectives were not obtained in the *1A* due to its failure to go into orbit, certain improvements were indicated. The satellite description contained in this report is applicable to both the *1A* and the *1B* except for certain circuit changes, some of which are described herein. Transit *1B* contains twice the number of solar generators provided in the *1A*. An unmodulated 324-mc carrier replaces the modulated 108-mc carrier used in *1A*. The 108-mc telemeter with its associated power supplies is deleted, and a multiplier circuit (designated *C* system in the *1B*) added. Approximately one-half the silver-zinc power supply has been eliminated and the nickel-cadmium batteries have been removed from the solar-cell panels and installed in the former location of the silver-zinc batteries. A permanent magnet is installed to ensure that the satellite will not dwell in an unfavorable position particularly with regard to the solar-cell system. A permeable material is also included to eventually damp out any residual spin motion.

DESIGN—FUNCTIONAL CONSIDERATIONS

Basic Instrumentation. Four harmonically related frequencies were used from a dual transmitter system operating from a specially designed, single-broadband antenna. Power was supplied from two independent sources, one chemical and one solar. Additional equipment redundancy was provided by the use of dual telemetering systems and dual de-spin timers in order to assure that the test objectives would be achieved.

It is expected that a few months of signal reception and analysis will suffice for the refraction experiment. Because a satellite at the orbital altitude desired (400-500 nautical miles) will have a continuing value for other related purposes, notably geodetic determinations, it was decided that the basic instrumentation should consist of two transmitters powered by a chemical power supply, (silver-zinc cells) of a few months' duration and of two more transmitters operating from a solar-cell nickel-cadmium supply of indefinite life, but capable of being deactivated or reactivated from a ground transmitter. The major requirement of the transmitters is that they be extremely stable—in the sense that their frequencies not drift substantially during the time interval of reception by a tracking station. High absolute stability, although convenient to the analytical process, is not required. In order to ensure the highest possible reliability, the electronics have been divided into two

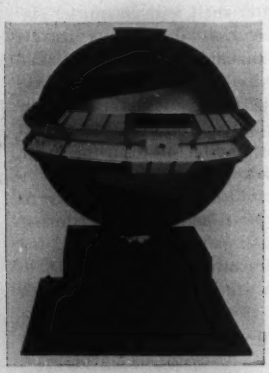


Fig. 2. (above) First navigational satellite.

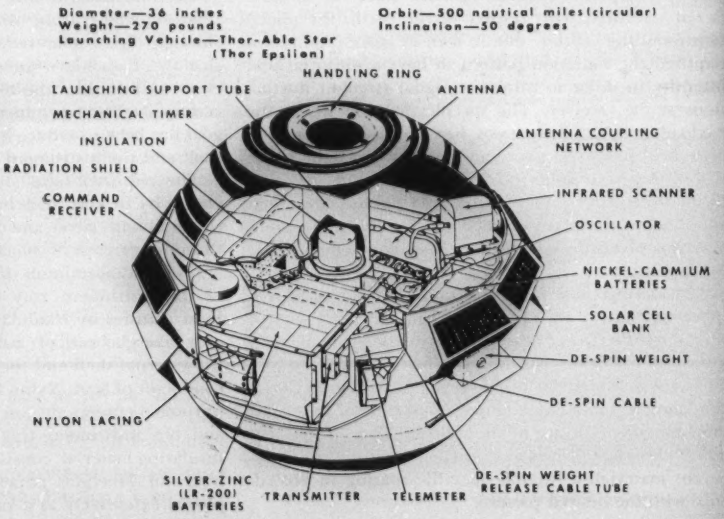


Fig. 3. (*right*) Transit 1B satellite cutaway view.

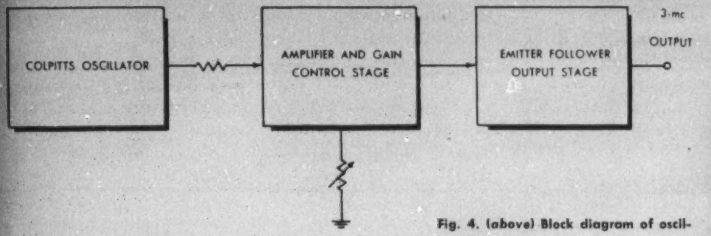


Fig. 4. (above) Block diagram of oscillator circuitry.

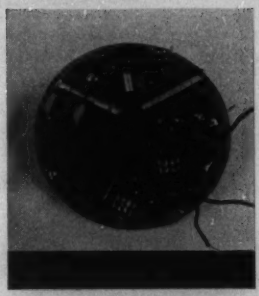


Fig 5. (right) Oscillator circuitry.

systems which are completely independent except for sharing a common antenna (Fig. 1).

Configuration. The probabiliy of accomplishing a sustained orbit in a launching attempt is not as favorable as one might wish, and the probability of attaining the desired circular orbit is, of course, even less favorable. In particular, there was concern that the value of the experiment might be nullified if a relatively low orbit, or the more likely possibility, if a highly elliptical orbit dipping into a trace of atmosphere, should result. The use of the Doppler shift in the fashion described requires a knowledge of the equations of motion of the satellite. Consequently, it is necesary that any aerodynamic drag present be accounted for. Estimates of the air density at orbital altitudes have been revised considerably in the last 2 years and probably can be refined further. Therefore, in order to give to the satellite a constant and predictable drag coefficient, regardless of the satellite's altitude, a spherical shape was selected.

Antennas. The use of four frequencies (over a 4-to-1 frequency range of 54 to 216 mc) necessitated either the use of a broadband transmitting antenna[5] or the complexity of separate antenna systems. Since the satellite is not stabilized with respect to the earth, the uncertainties of the attitude due to spin or space orientation required the radiation pattern to have a uniform field intensity in order to minimize signal strength fluctuations at the receiver. The specifications on which the payload antenna design was based called for peak-to-peak field intensity variations of not more than 10 db within the entire spherical co-ordinate system. Another factor to be considered was the need for flush-mounted antennas to eliminate extended dipole elements or other radiating protrusions with their accompanying mechanical problems.

Considering these facts, and taking into account the spherical shape of the satellite, an antenna was designed which resulted in a nearly uniform radiation pattern (isotropic radiator) over the entire spherical surface. This was achieved by utilizing the current and phase distributions of an equiangular (logarithmic) spiral slot over the entire surface of the sphere.[5] The slot was obtained by depositing on the sphere, which is of r-f transparent material, a suitable metallic coating in accordance with the desired pattern.

De-Spin. The launching rocket vehicle for which the satellite was designed employs spin stabilization of the third and final stage of rocket propulsion. Upon injection of the satellite into orbit and separation from the expended third stage, the satellite possesses a high rate of spin which, if not removed, would make Doppler analysis very difficult, if not impossible. On the other hand, some small amount of rotation is desirable to ensure exposure of the solar cells to an average, rather than to a possibly adverse, sunlight incidence. Similarly, avoidance of temperature gradients from one side of the outer skin to the other requires some rotation.

As a means of reducing the initial high rotational velocity to a slow, specified amount, a de-spin system is employed which consists of a pair of weights attached to lanyards wound around the satellite at its equator. In response to a timer signal, the weights are released and deploy along involute curves due to centrifugal force, thereby providing a restraining torque (through the lanyard attachments) which quickly retards the satellite's spin. By this process the satellite's total angular momentum is transferred into the weights.

Thermal Design. The outer shell will encounter significant temperature differentials during its travels through direct solar radiation and through the earth's shadow. To achieve the desired performance, it is necessary to minimize the temperature fluctuations within certain satellite equipment. Therefore, a critical design goal has been to reduce heat transfer between the outer shell and the instrument package.

The required ratio (1.0) of thermal absorptivity to emissivity of the shell has been achieved by painting the shell with silver and black paints. Silver is used for the antenna pattern, black for other areas.

Insulated aluminum discs are installed on both sides of the instrument tray as thermal radiation shields. Heat transfer by conduction is minimized through use of a Fiberglas support tube. The nylon lacing between the external shell and the instrument tray is also a poor conductor of heat. Nylon lacing is also used for the same purpose between the oscillator package (Dewar flask) and the instrument tray. A novel and very effective insulating material, consisting of a sandwich of alternate layers of Fiberglas paper and aluminum foil, is employed extensively as a radiation barrier.

Structure, Weight, and Balance. The weight limitations are those imposed by the launching vehicle for the orbit desired and in the case of Transit were 265 ±5 pounds.

The structure is, of course, designed to withstand launching accelerations and vibrations. It is described in subsequent paragraphs.

DESCRIPTION

Structure. The payload assembly is made up of three major structural units: (a) the external shell, (b) the central support tube, and (c) the instrument tray (wheel-package structure). Figs. 2 and 3 depict respectively the external appearance and a cutaway view of the satellites.

The spherical shell consists of two hemispheres constructed of ¼-inch cell nylon phenolic honeycomb core material sandwiched between two surfaces of Fiberglas cloth impregnated with an epoxy resin. Mounted peripherally about the equator are the solar generator panels and adjacent to these are panels which contain the nickel-cadmium cells.

Internally, all satellite instruments are housed in a wheel-shaped aluminum-sheet-metal-tray structure. The tray is installed in the equatorial plane. In addition to the support offered by the tube, the instrument tray is tied to the external shell by nylon lacing about the equator. Equipment in the tray is symmetrically distributed to facilitate balance. A high degree of dynamic balance is necessary to minimize eccentric loading during launching and the subsequent spin-up operation.

Transmitters. The *A* system transmitter (Fig. 1) consists of an ultra-stable crystal oscillator, a frequency-multiplier chain, and two r-f power amplifiers operating at nominal frequencies of 54 and 108 mc. Each transmitter is capable of a power output of about 200 milliwatts (mw). An 8-channel telemetering system periodically inscribes information bursts on the 108-mc carrier in the form of a pulse-width-modulated pulse train. The *A* system transmitter is powered by a silver-zinc storage battery having a life of approximately 90 days.

Power is supplied to the *B* system from nickel-cadmium storage batteries which are in turn recharged by a bank of silicon solar cells. Because of the potentially long life of the *B* system, two command receivers are included which permit turning off the system from the ground. These receivers are coded to prevent accidental actuation.

Stable Crystal Oscillators. Each satellite contains two ultra-stable crystal oscillator units designed to meet the following requirements:

1. Short term stability of 1 part in 10^8 for any 30-minute period during the life of the satellite.
2. Long-term stability of 25 parts in 10^6 for 3 months.

In order to meet these requirements, special mechanically rugged *AT*-cut 3-mc crystals have been supplied. A crystal and its associated circuitry are mounted in a double Dewar flask, which is evacuated as the satellite leaves the earth's atmosphere. The transistorized oscillator, as indicated in the block diagram of Fig. 4, consists of a Colpitts-type circuit employing a transistor. The crystal operates in a fundamental mode at series resonance in the feedback loop between the emitter and the tank circuit. The low phase slope of the transistor at 3 mc contributes to the frequency stability of the circuit. The oscillator is isolated from the following stages by a resistor. A silicon diode across the tank circuit limits crystal drive level and thereby helps stabilize the frequency against power supply variations. A 2-stage avalanche diode regulator also holds the base voltage constant.

A common emitter amplifier following the buffer resistor raises the output voltage to a usable level. A variable emitter degeneration resistor is employed as a gain control device. An emitter follower output stage is also provided to keep the drive level constant at the frequency multiplier input. The oscillator shown in Fig. 5 is constructed on a printed circuit board which fits in the outer Dewar flask. The crystal itself is placed in the inner flask. Provisions are made to adjust the amplitude and frequency of the oscillator from the outside of the Dewar flask. The crystals are tailored at the factory to specified frequencies so that only slight adjustment is necessary to set the frequencies exactly.

Frequency Multipliers. Two frequency multipliers are included in each satellite, one driving the 54- and 108-mc transmitters from one stable oscillator, the other driving the 162- and 216-mc transmitters from the other oscillator.

Each frequency multiplier accepts the 3-mc stable oscillator output and by a series of frequency doublers and triplers produces two 54-mc output signals at a power level of several milliwatts. Each output drives a power amplifier.

The frequency multiplier circuitry is constructed on a printed board and is then potted in plastic foam to

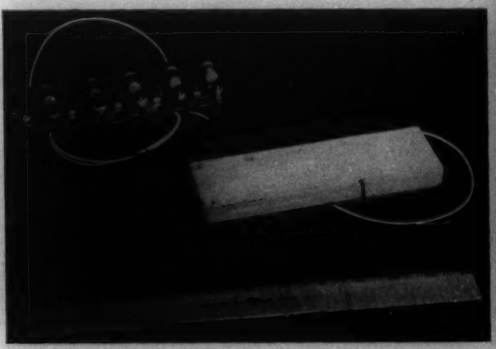


Fig. 6. Frequency multiplier circuitry (unpotted and potted).

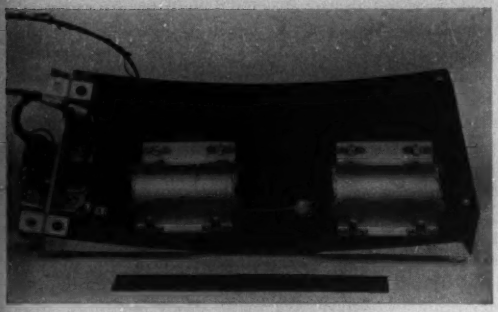


Fig. 7. Nickel-cadmium cells.

increase its vibration resistance. Both unpotted and potted units are shown in the photograph of Fig. 6.

Power Amplifiers. The 54-mc power amplifier employs a diffused base transistor operating as a Class *AB* common emitter amplifier. The amplifier supplies approximately 200 mw of power to the 50-ohm antenna matching network when driven from a 25-mw source. The 108-mc power amplifier consists of a Class *B* frequency doubler driving a Class *AB* common emitter power amplifier. This power amplifier also supplies about 200 mw of 108-mc power to the antenna matching network when driven by 25 mw of 54-mc energy. Point-to-point wiring is used in its construction to achieve the low stray capacitances and inductances required for proper circuit operation.

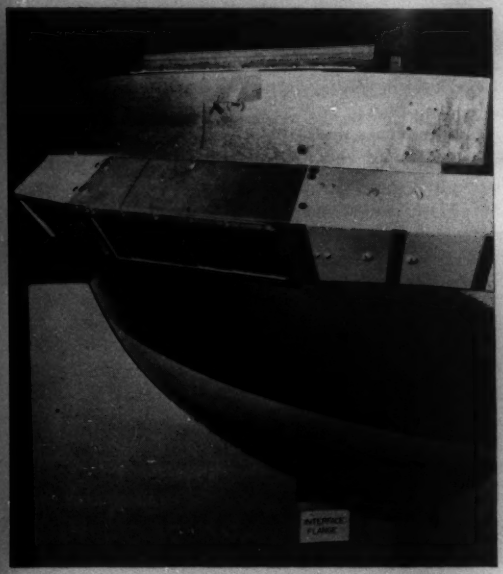


Fig. 8. Bank of solar generators mounted on satellite.

Telemetering Systems. Two 8-channel pulse-width telemetering systems are employed, one each for the *A* and *B* systems. System *A* modulates the 108-mc transmitter while System *B* modulates the 162-mc carrier. Each system uses two of the eight channels for inflight calibration, thus leaving six active channels per telemeter. Inflight calibration is designed to provide a means for correcting errors resulting from power-supply voltage variations, core-temperature effects, etc.

The functions telemetered are satellite environmental temperatures on the outer shell, temperatures of various electronic components and structures within the satellite, and the temperature and performance of the solar-cell windows. Thermistors are used as sensing elements throughout. Transistors and square hysteresis-loop cores are the active elements in each telemeter.

Command Receivers. Ground-controlled dual-conversion crystal-controlled transistorized receivers in parallel turn off and turn on the solar-powered *B* system.

Power Supplies. The satellite electronics are powered from a number of separate energy sources for maximum reliability and minimum interference between systems. Redundant wiring is employed to increase reliability.

The *A* system is powered by two 12-cell (100-ampere-hours each) silver-zinc batteries in parallel assembled in four separate pressurized compartments. The 108-mc telemeter system operates from four *D*-size nickel-cadmium cells. These cells are hermetically sealed units with a welded glass-to-metal seal on the top of the cell case.

The *B* system operates from 15 *D*-size nickel-cadmium cells. The cells are mounted on sheet metal panels exterior to the sphere (Fig. 7) and constitute a tapped battery, thus directly providing the necessary voltages for the electronic equipment. This battery is maintained fully or nearly fully charged by a bank of 12 solar generators (Fig. 8). The generators plus one experimental unit are arranged on two 12-sided rings near the equator of the satellite (Figs. 2 and 3). Each generator bank consists of 70 series-connected silicon photovoltaic converters mounted on an aluminum sheet-metal structure by a ceramic cement. The cells are protected from micrometeoritic damage by fused silica windows.

A solid electrolyte battery charges a capacitor to detonate the squib-operated wire cutter of the de-spin mechanism. The entire system (battery, capacitor, timer, squib, and wire cutter) constitutes an integrated unit.

TESTING

THE TEST PROGRAM was established with the objective of developing a sequential series of tests which when completed would culminate in the reliability required for a high probability of successful satellite performance in orbit.

To achieve this reliability the test conditions were predicated on (but did not necessarily duplicate) the

Table I—Environmental Test Conditions (Assembled Payloads)

Vibration					Centrifuge				Hot and Cold Cycle			Hot Soak			De Spin	
Type Freq. (cps)	Amp.	Duration	Position	Remarks	g's	Duration	Position	Remarks	Temperature Limits F	Duration	Remarks	Temp. Limits Skin	Duration	Remarks	Spin Rate	Remarks
5-15 15-20 20-50 50-1,000 1,000-2,000	0.2" pk 5g pk 5g rms 7g rms 9g rms	Increase ½ octave per min	vert.	See note 1	24 g vert. concurrent with 3 g transverse	30 sec.	six horizontal		−65F to +55°F on skin	20 hot & cold cycles each 58 min of arc lights on followed by 39 min of cooling	See note 3 Satellite will rotate at 1 rpm in vert. pos.			See note 3	225 ±5 rpm	De-spin mechanism should cause spin deceleration from 225 rpm to 1 rpm in 1.2 sec.
20-2,000	0.07g²/cps rms	4½ min	vert.	See note 2								Arc lights on continuously	14 days	Satellite vert. & rotating		
5-15 15-50 50-1,000 1,000-2,000	0.2" pk 3g rms 4g rms 5g rms	Increase ½ octave per min	hor.	See note 1								Arc lights on continuously	14 days	Satellite vert. & non-rotating. Performed in each of 3 positions		
20-2,000	0.05g²/cps rms	4½ min	hor.	See note 2												
Acceptance																
5-100	1g rms	1 min plus 1 min at resonance	vert. & repeat in hor.	See note 1	19.8± 1g vert. concurrent with 1.5± .5g	30 sec.	hor.	Not Mandatory	150 F −39 F skin	1 hot & 1 cold cycle	See note 3 Satellite rotate at 1 rpm in vert. pos.	Not applicable			Not applicable	
20-2,000	0.07g²/cps rms	1 min	vert.	See note 2												

Note 1: Sinusoidal forcing function; Note 2: Random forcing function; Note 3: (a) Performed in vacuum chamber with pressure at 0.5 micron Hg or lower; (b) Internal walls of chamber −200 F for type test and −100 F for acceptance tests; (c) a/e tests and measurements made during these type test series.

environments of shipment, handling exposure at the launch site, launching and orbiting, plus a standard acceptance regime to demonstrate proper workmanship and manufacturing techniques. The above procedures are common to most test programs, including the missile programs of the Applied Physics Laboratory, and differ from customary practices only in those details peculiar to an earth satellite plus the exigencies of time, budget, and test equipment restrictions.

There are basic differences between guided missiles and this satellite, not of an environmental nature, which have impact on the test philosophy. One is that this satellite is in the development phase and, even when operational, will require manufacture of only small numbers of units, whereas guided missiles are typically produced in large quantities. Another is the complexity of the missile due to its guidance, control, and fuzing systems; in contrast, this satellite has simple electronics and few mechanical operations.

TEST PROCEDURES

TABLE I PRESENTS the conditions prescribed for type and acceptance testing of assembled satellites. The conditions have been selected on the basis of theoretical studies and predictions, and on the result of flight-test experimental data. In order to compensate for variations in mechanical rigidity and for stress and resonances generated or transmitted by the structure itself, it was decided to subject the components to a more rigorous environment than they are likely to encounter during launching or in orbit. This should improve the probability of successfully accomplishing the test.

Specific examples of the progressive phases from design evaluation tests through routine acceptance may be seen as applied to the transmitter. Tests were run on the oscillator flask to determine its mechanical integrity; these resulted in improvements in the method of internal mounting. The crystal received extensive vibration and acceleration tests under conditions that would simulate its environment when installed in the flask. Combined temperature and vacuum tests, extending through periods of weeks, were made with the components breadboarded, then packaged but unpotted, then as a prototype, and then as an integral unit of an assembled satellite. A complete functional check of all systems was made during satellite acceptance tests through radio transmission to the APL receiving station.

Acceptance testing of a complete satellite involves only "go–no–go" operation in a testing program which encompasses all subsystems. For example, while the command receiver is in a "ready" condition, the only way to determine whether its sensitivity has experienced degradation or whether a catastrophic failure has occurred is to transmit a coded r-f signal (which is part of the procedure) and note the response of the circuits. The simplicity of the satellite electronics, coupled with the small number of units needed, eliminates the need for an intricate and costly data-gathering and processing system during testing. The data gathered during design and type testing is more comprehensive in detail and scope than that of acceptance.

Thermal Testing. While the vibration and centrifuge tests are of a routine nature, the temperature cycling and absorptivity-emissivity (a/e) tests deserve more mention. Absorptivity-emissivity is the ratio of absorptivity of solar energy to the emissivity in the infrared of the satellite coatings. It is particularly significant in satel-

Fig. 9. Vertical vibration test on Transit 1B.

lites since the a/e value determines the temperature limits and cycle characteristics to which the instrumentation is subjected. Restricting the temperature extremes is essential to insure proper power-supply performance and to minimize transmitter frequency drifts. The tests are conducted in a vacuum chamber whose dimensions are sufficient to allow installation of the satellite on a stand which permits satellite rotation. Temperature limits of the satellite are controlled by incandescent lights turned on and off in a preset program. The chamber walls are cooled to —100 F by freon to simulate outer space radiation losses. The tests are conducted under a vacuum of 2×10^{-5} mm of mercury so that the radiative and convective heat transfer in orbit can be realistically simulated, an important requirement for achievement of accurate thermal gradients and a/e data. The a/e measurements require a solar spectrum source or its simulation such as carbon arc lights rather than the incandescent lamps mentioned above.

The experiment is performed in three parts.[6,7] First, the intensity of the carbon arc in the vicinity of the satellite in the chamber is measured with calorimeters. Secondly, the energy exchange to the chamber walls is determined by using a test sphere of $a/e = 1$ mounted in the chamber and illuminated with the previously calibrated arc. A photocell monitoring the arc aids in obtaining constancy of arc intensity. Third, the test sphere is removed, replaced with the satellite and the test repeated. The satellite is rotated while exposed to the arc and its surface temperature recorded when stabilized. The data are used in the following equation whose solution gives the desired measurement:

$$\frac{a_s}{e_s} = \frac{4}{E_A}\left(\sigma T_s^4 - E_W\right)$$

where

a_s = absorptivity to solar spectrum of satellite
e_s = emissivity to infrared of satellite
E_A = energy flux of arc beam
σ = Stephan-Boltzman constant
T_s = temperature "of shell"
E_W = net energy flux to or from chamber walls

TEST EQUIPMENT

Vibration. The shaker for satellite assemblies is an *MBC25H* multipurpose type which can supply both vertical and horizontal motion. It is rated at 3,500 pound-force capacity. It is used in conjunction with a Panoramic Sonic Response Indicator, which provides a frequency-scanned signal of constant amplitude once every second, or a General Radio type *1390A* "white noise" generator, whose output is a random signal of flat spectral density and Gaussian distribution. Other shaker control equipment includes band-pass filters, peak-notch equalizers and amplifiers.[9]

Fig. 9 illustrates the Transit *1B* undergoing vertical vibration tests.

Thermal Vacuum. One of the major test devices for simulating orbital conditions of the satellite is the vacuum-thermal test chamber. It is a cylindrical chamber 7 feet long with a 6-foot inside diameter. The chamber and its pumping and auxiliary equipment are basically designed as vacuum coating equipment by the Consolidated Electrodynamics Corporation.

The pumping is effected by the use of large mechanical pumps to lower the pressure to approximately 0.2 mm of mercury; diffusion pumps are used to reduce the pressure further. The latter, when used with butyl phthalate fluid, can cause a reduction from atmospheric pressure to 0.5 micron (5×10^{-4} mm of mercury) in 5 minutes in an empty, clean chamber.

Major additions to the external chamber walls were made by the Laboratory to provide temperatures ranging from +120 F to —100 F, when electrically heated in the former case or cooled with freon in the latter.

REFERENCES

1. A Satellite Doppler Navigation System, W. H. Guier and G. C. Weiffenbach, *Proceedings*, Institute of Radio Engineers, New York, N. Y., April 1960.

2. Theoretical Analysis of Doppler Radio Signals from Earth Satellites, W. H. Guier, G. C. Weiffenbach. Bumblebee Report No. 276, April 1958, Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Md.

3. Measurement of the Doppler Shift of Radio Transmissions from Satellites, G. C. Weiffenbach. *Proceedings*, Institute of Radio Engineers, New York, N. Y., April 1960.

4. The Tracking of Satellites by Doppler Methods, W. H. Guier. International Space Symposium, Nice, France, Jan. 1960.

5. A Broad Band Spherical Satellite Antenna, H. B. Riblet. Applied Physics Laboratory, The Johns Hopkins University.

6. Use of Vacuum Chamber to Determine a/e of Satellite Surface, EM-2966/CLS-42, *Ibid.*, May 1958.

7. Transit — Outline of Cold and Hot Cycle Test Procedure for Operating Satellites, EM-2997, *Ibid.*, July 1959.

8. Energy Dissipation Due to Motion of Liquid in Satellite Batteries. CLS-96, *Ibid.*, July 1959.

9. Vibration and Acceleration Tests of Structural Mock-up of Transit Satellite. CLS-113/ETR-258, *Ibid.*, Aug. 1959.

Nonlinear Servomechanism of Limited Dynamic Range

R. L. MORUZZI
ASSOCIATE MEMBER AIEE

F. B. TUTEUR

THE METHODS of analysis and synthesis of linear feedback control systems have now reached such a state of perfection that the design of a system to meet any set of performance specifications should be a fairly simple matter. Unfortunately, no practical system can be completely linear and, therefore, the theory developed for linear systems applies only approximately to practical systems.

A particular type of nonlinearity frequently encountered is dead band. A device having dead band will not respond to signals that are smaller than a certain threshold level. In mechanical systems, dead band is often caused by coulomb or dry friction. Another commonly encountered type of nonlinearity is saturation. Inasmuch as no physically realizable component can deliver infinite output, all practical systems saturate. A device having both dead band and saturation may be thought of as having a limited dynamic range; that is, it responds in an approximately linear fashion only to signals large enough to exceed the dead-band threshold, but not so large as to cause saturation. The dynamic range may, in fact, be defined as the ratio of saturation level to dead-band level. For maximum performance of a feedback control system, the servo motor or other power element should have as large a dynamic range as possible. On the other hand, the cost of a motor generally increases with dynamic range, particularly if an effort is made to increase the dynamic range to its ultimate limit. Thus, to keep the cost of a system within reason, a motor with limited dynamic range must be employed. Limited dynamic range of one or more elements of a feedback control system generally affects the relative stability of the system, and it may, in fact, cause actual instability. Consequently, the static accuracy of such a system has a definite upper limit. In addition, systems of this type generally exhibit a cut-off frequency; that is, for all frequencies above a given critical frequency, the system fails to respond irrespective of the magnitude of the input signal.

A common unit having limited dynamic range is the combination of a saturating power amplifier and a d-c motor having stiction or static friction T_s and coulomb friction T_c. Analysis of this system shows that the describing function for different values of T_s/T_c are all quite similar in form. It is, therefore, possible to construct a boundary curve surrounding all the describing functions. This boundary curve is referred to as the describing function envelope and it may be used as a rather conservative but simple stability criterion. The describing function envelope shown in Fig. 1 encompasses all describing functions for T_s/T_c between 1 and 10. The describing functions for $T_s/T_c > 10$ differ by only a negligible amount from those for which $T_s/T_c = 10$, so the boundary of Fig. 1 essentially includes all describing functions.

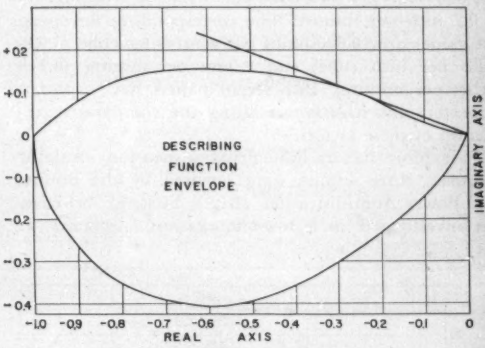


Fig. 1. Describing function envelope.

The criterion obtained using the describing function envelope is conservative because intersection of the Nyquist diagram with the envelope does not necessarily mean that the system will be unstable. This is due both to the frequency dependence of the describing function and the fact that for specific values of T_s/T_c the describing function for all frequencies may be far away from the envelope. The criterion is, however, desirable not only because of its simplicity, but also because in most practical cases the exact value of T_s/T_c is unknown and may even change during operation.

The use of the describing function envelope makes it possible to obtain rapidly conservative estimates in terms of relative stability, the effect of series equalizing networks, the effect of minor loop equalization, the combined effect of series and minor loop equalization, and static error.

In addition, investigation of the general shape of the describing function makes it possible to make a number of qualitative statements concerning overall system frequency response and relative stability as defined by M_{max} and ω_{max}. It is also possible to evaluate the effect of cut-off frequency.

Digest of paper 60-862, recommended by the AIEE Feedback Control Systems Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Summer General Meeting, Atlantic City, N. J., June 19-24, 1960. Scheduled for publication in AIEE *Applications and Industry*, 1960.

R. L. Moruzzi is with Worcester Polytechnic Institute, Worcester, Mass.; F. B. Tuteur is with Yale University, New Haven, Conn.

Rainfall Resistivity and 60-Cycle Insulator Flashover

R. J. MATHER
MEMBER AIEE

M. G. POLAND
MEMBER AIEE

DISCUSSIONS between American and European standards groups are currently directed toward adoption of uniform parameters for wet flashover and wet withstand tests. American published values are based on tests conducted with a spray water resistivity of 7,000 ohms per inch cube and a rate of precipitation of 0.2 inch per minute. The corresponding European test values are 10,000 ohms per centimeter cube (3,930 ohms per inch cube) and 3 mm per minute (0.118 inches per minute). Two recent papers have reported laboratory investigations relating the comparative influences of these factors.[1,2]

To explore factors influencing suspension insulator flashover, three studies were pursued by the Bonneville Power Administration (BPA). First, ice bridging was investigated in a low-temperature laboratory at

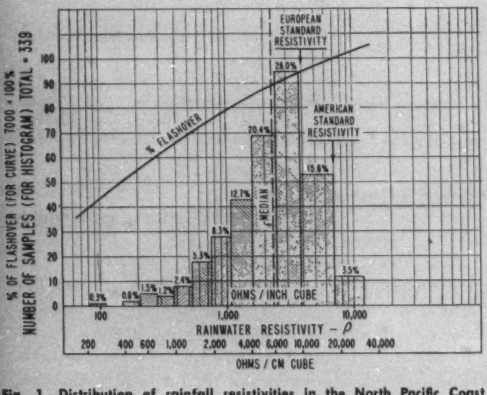


Fig. 1. Distribution of rainfall resistivities in the North Pacific Coast area.

Washington State University. The tests verified a significant reduction of flashover due to the ice bridging between units and emphasized the critical influence of the rainwater resistivity. Second, a program was initiated to determine resistivities which may occur in actual rainfalls for all seasons of the year in the North Pacific states. Third, since little test information was available as to the wet flashover with very low spray water resistivity, an investigation of this factor was made at the McMillan High Voltage Laboratory, Oregon State College.

There were 339 rainfall samples obtained at 26 BPA substations. Samples were collected near the start of a rainstorm and after a period of days with no rain. The distribution of resistivities of these samples is shown by the histogram. The class intervals on the abscissa are not uniform in length but are selected at the 5% points of the computed flashover voltages. It must be emphasized that this frequency distribution applies to the resistivity of the precipitation during the early period of a rainstorm which is frequently the critical time with respect to insulator flashover.

The wet flashover tests were performed with distilled water initially and the resistivity reduced by the addition of sodium chloride. Test results indicated that the reduction in flashover is not a straight line function with respect to the logarithm of the spray water resistivity as previously assumed. The solid curve in the figure is derived from the test values using the American Standard rate of precipitation. The equation for this curve is

$$Y = [\,-0.5668 + 0.6029 \log\rho - 0.0504\ (\log\rho)^2\,] \times 100$$

where

Y = flashover as a percent of the published values for 7,000 ohms per inch cube

ρ = spray water resistivity in ohms per inch cube

Note that the reduction in flashover may be as great as 50% within the range of rainfall resistivities obtained. Also, the American and European standards are too high to be representative of actual rainwater resistivity which may occur at the start of a rainstorm. This does not imply that a lower standard would be preferable. One objective of a standard is to establish test conditions that will facilitate duplication of results by various investigators. From this standpoint Kingsbury reports that the deviation of test results is less with the higher American standard.[2] However, it should be recognized that the published wet flashover values may be unrealistically high under certain atmospheric conditions.

Similar field samples of rainfall now being collected by utilities in other regions of the United States will prove valuable in evaluating the significance of these data.

Digest of paper 60-831, "Effect of Rainfall Resistivity on Sixty-Cycle Wet Flashover of Suspension Insulators," recommended by the AIEE Transmission and Distribution Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Summer General Meeting, Atlantic City, N. J., June 19-24, 1960.

R. J. Mather and M. G. Poland are with the U. S. Department of Interior, Bonneville Power Administration, Portland, Ore.

REFERENCES

1. The Influence of Water Resistivity and Precipitation Rate Upon Sixty-Cycle Wet Flashover Voltage, AIEE Committee Report. AIEE *Transactions*, pt. I *(Communication and Electronics)*, vol. 77, July 1958, pp. 350-57.

2. A Comparison of European and American Wet Flashover Test Methods, B. E. Kingsbury. AIEE *Power Apparatus and Systems*, June 1960, pp. 271-77.

Use of Moon or Satellite Relays for Global Communications

L. P. YEH

Both moon and satellite relays offer feasible means to extend the range of global communications. Advantages and limitations of each relay are discussed, with the moon relay the slight favorite at our current level of technological development.

THE RANGE of global communications by a single radio link has been limited, in the past, by the ionospheric mode of propagation for the very high frequencies, and by the ground wave mode of propagation for the very low frequencies.

There is a possibility, however, of extending the range by means of moon or satellite relays. This article investigates this possibility from the practical system performance point of view.

MOON RELAY

Range vs. Usable Time. As shown in Fig. 1, the plane of the moon's orbit around the earth is inclined to the plane of the ecliptic (the earth's orbit around the sun) at an angle of about 5.1 degrees, the earth's axis is tipped

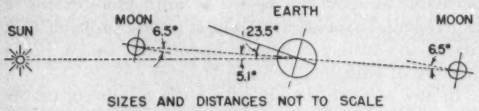


Fig. 1. Relation between earth's and moon's orbit.

about 23.5 degrees from the perpendicular to the ecliptic, and the moon's axis is inclined about 6.5 degrees from the perpendicular to the plane of its orbit. In addition, the period of the earth's revolution around the sun is about 365 days, while that of the moon's revolution around the earth is only about 27 days.

Because of these astronomical complexities, the usable time of moon relay—the total time per day during which two stations on the earth's surface can see the moon simultaneously—varies from day to day by amounts depending on the longitudes and latitudes of the two stations. Daily periods during which moon relay is possible at Greenwich meridian can be derived from the times of moonrise and moonset obtained from the "American Ephemeris and Nautical Almanac"[1] for latitudes from +60 to −60 degrees, or from "The Air Almanac"[2] for latitudes including the polar regions. For longitudes other than that of Greenwich, a method of obtaining the local time of moonrise and moonset is given in "Navigation and Nautical Astronomy."[3]

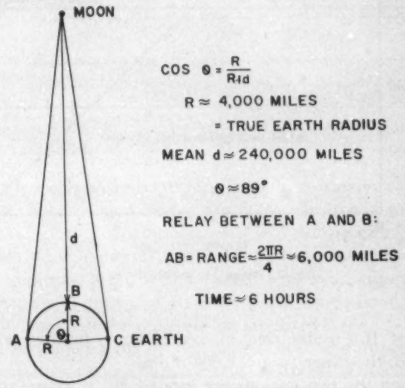


Fig. 2. Moon relay geometry at the equator.

The range of moon relay (great circle distance) may be computed from the known longitudes and latitudes of the two stations.[4]

A definite relation exists between the range and usable time of moon relay between two earth stations. Simple cases when both stations are located at the equator or at the same longitude will serve as good examples.

The moon relay geometry at the equator, considering the earth as an idealized spere, is shown in Fig. 2. If the mean distance between the earth and the moon is taken as 240,000 miles, and the earth's radius as 4,000 miles, the angle θ is approximately equal to 89 degrees. Relay between stations A and B has a range of approximately 6,000 miles and a usable time of about 6 hours per day, assuming that both transmitting and receiving antennas are steerable to follow the moon. However, one can trade range for usable time.

The relation between range and usable time is illustrated in Fig. 3. If the two stations (A and C in Fig. 2) are 12,000 miles apart, or approximately half the circumference of the earth, relay is impossible because the two stations can see the moon simultaneously at only one

Abridged text of paper 60-1064 presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the Aero-Space Transportation Committee. Scheduled for publication in AIEE *Communications and Electronics*, January 1960.

L. P. Yeh, formerly with General Electric Company, Philadelphia, Pa., is now with Page Communications Engineers, Inc., Washington, D. C.

The work covered by this article was initiated while the author was with Electronics Division, Westinghouse Electric Corporation, Baltimore, Md., and completed at Aerosciences Laboratory, General Electric Company, Philadelphia, Pa.

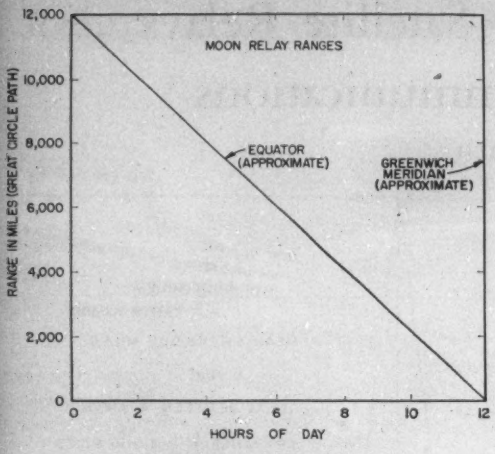


Fig. 3. Range vs. usable time.

instant. If a usable time of, say, 10 hours per day is required, the range is only 2,000 miles.

When the two stations are located at the same longitude, range and usable time are independent. The usable time is about 12 hours for all ranges up to about 12,000 miles—half the circumference of the earth.

In general, therefore, the usable time of moon relay between two earth stations varies from zero to 12 hours per day, and the range varies from zero to 12,000 miles.

Moon Echoes. The first use of radar equipment to obtain echoes from the moon was reported independently by the U.S. Army[5] and Bay[6] of Hungary. Subsequently, experimental work has been carried on in Australia,[7, 8] England,[9] and the United States.[10, 11, 12] The possibility of obtaining moon echoes is well confirmed today.

Some conclusions may be drawn from these experiments:

1. For continuous wave (cw) and long pulse signals (1,000 μsec or longer), the effective echo area of the moon may be considered as 0.1 of the projected area. For shorter pulses, the pulse elongation effect should also be considered.

2. A circuit loss of 250 db between isotropic antennas for 100 mc, and a 6-db increase of loss per octave increase of frequency may be used for future moon-echo system design using long pulses or cw. For pulse lengths shorter than 1,000 μsec an additional power reduction factor t/T should be used.[13, 14, 15] (t = pulse length in microseconds and T = 1,000 μsec.) Fig. 4 shows the moon circuit loss obtained from the experiments for various frequencies, and Fig. 5 the power reduction factor in db for various short pulse lengths.

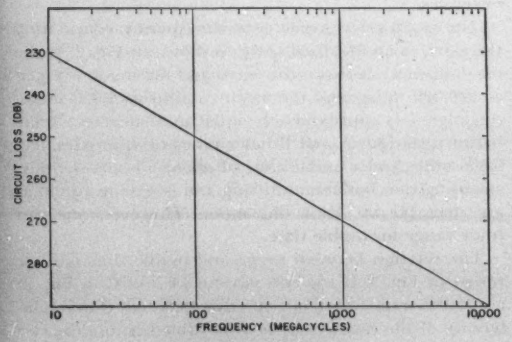


Fig. 4. Moon circuit loss.

System Considerations. Two types of moon relay are possible: using the moon as a passive reflector, and using the moon as an active repeater station. At present, only passive relay is feasible; active relay must wait until equipment can be set up on the moon.

The use of the moon as a passive reflector for earth-to-earth relay has been thoroughly analyzed theoretically by Grieg et al.[13] It was concluded that the most important consideration for such a system is the moon's surface. If the moon is smooth, there is no limitation to the type of transmission possible—telegraphy, voice, or wide-band. On the other hand, if the moon is rough, essentially only narrow-band telephony and telegraphy can be accommodated.

Experiments over many decades have concluded that the moon's surface is rough for optical frequencies. Whether this is also true for radio frequencies is highly debatable and can not be settled until more extensive experimental data are available. It is most probable that the moon's surface is neither smooth nor rough, but a mixture of both.

In any communication system the minimum usable carrier-to-total-noise power ratio (the threshold) is of utmost importance. This ratio determines whether the input signal can be detected in the presence of noise associated with the receiver input, including the antenna system. This is the first limitation on the system performance.

In the region of 100 to 10,000 mc, considered feasible for moon relays, the thermal noise inherent in the receiver predominates at isolated locations where the receiver terminals are likely to be located. The following discussion is limited to thermal noise only.

The minimum usable carrier-to-noise power ratio depends on the modulation techniques used. For practical system design, a value of 15 db seems to be an average acceptable figure.

Fading and System Reliability. The moon echo experiments indicate that the received signals are subject to continuous fading of 20 db or more at both slow and fast rates. The slow fading, with a period of an hour or less, is believed due to the Faraday effect (the plane of polarization of the radio waves is rotated as they traverse the ionosphere in the presence of the earth's magnetic field). This effect has been reported to vary

inversely between the first and second power of frequency. Above 400 mc the effect seems negligible.

The fast fading, with a period of seconds or longer, is believed due to moon's libration (an apparent oscillation of the moon's face, as seen from a point on the earth, arising from the diurnal rotation of the observer on the earth and from variations in the moon's orbit). Browne et al[9] have analyzed 2-minute sample recordings and found the fading distribution to be very close to Rayleigh. Moreover, atmospheric refraction in the troposphere and multipath effects may also have some bearing on the fading of the received signal. Therefore the fading characteristic is a combination of many effects.

In general, a fading margin of 10 to 20 db or even more should be allowed for a workable system. Extensive signal level measurements on a long term basis are required to determine the more reliable statistical fading characteristics. In the present study, a 20-db fading (corresponding to 99% time of Rayleigh fading distribution) is assumed.

Doppler Shift. Another factor worth considering is the doppler shift of the carrier frequency resulting from the relative motion between the moon and the earth. For a round trip between earth and moon there is a double Doppler shift. The magnitude of the doppler shift depends on the location of the transmitting and receiving terminals, the frequency of operation, and the month and hourly period. A method of calculating this double Doppler shift is given by Grieg et al.[13] The maximum that can be expected at various frequencies is given by $3.5f \times 10^{-6}$ cycles per second (f is carrier frequency in cycles per second). It can be seen that for an upper uhf system, say 10,000 mc, the double Doppler shift may be as high as 35 kc. Although smaller Doppler shifts have been successfully compensated by several practical schemes, such large shifts require careful consideration.

Sample Calculations. The choice of frequency to be used for space communications has been discussed in another paper.[16] A sample calculation for a typical 2,000-mc system is shown in Table I. The system will, therefore, work 80% of the time. For a reliability of 99%, some means must be used, such as using a diversity system or increasing the power and antenna size.

SATELLITE RELAYS

Orbital Requirements.[17-20] Since the satellite must travel in the centrally directed force-field of the earth, its orbit lies in a plane passing through the center of the earth. There are three possible types of orbital planes: (a) Circumpolar—passing through the two poles of the earth; (b) Equatorial—passing through the earth's equator; and (c) Inclined—inclined at an angle to the earth's equator. If the angle of inclination is equal to the ecliptic angle, it is sometimes called the ecliptic plane.

Inasmuch as the orbital period is much shorter than that of the earth's rotation, the orbital path described

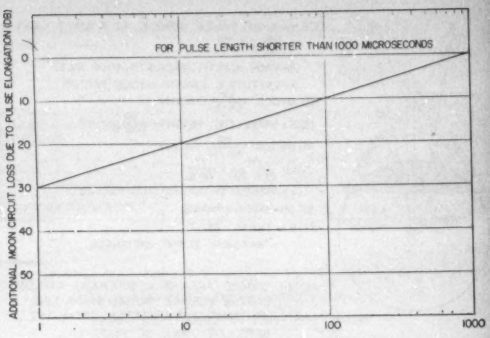


Fig. 5. Pulse elongation effect.

on the earth will not retrace itself in successive revolutions, but will look like a spiral inscribed on a sphere, so that even a circumpolar path will not lie exactly on a meridian. However, there is one exception—the case of equatorial orbit. When a satellite is in an equatorial orbit, it will remain at all times above the equator. This is the most ideal condition for satellite relays.

The shape of the orbital path is also very important. The path may be a "great circle," with the center of the earth as its center; or, more generally, a "great ellipse" with the earth's center as one of its foci. Whether the path is circular or elliptical depends on the injection conditions—primarily the injection velocity and angle. There is only one combination of injection velocity and angle that will cause the satellite to orbit in a circular path. Any slight errors will put the satellite in an elliptical orbit.

Another interesting aspect is the lifetime of the satellite. The most significant parameters that affect the lifetime are the frontal area density of the satellite and the atmospheric density. It is obvious that a large satellite at too low an altitude will not stay up long. Methods[20] have been proposed to calculate the lifetime of satellites in circular or elliptical orbits. Due to the difficulty in estimating accurately the atmospheric densities at altitudes of hundreds or thousands of miles, the calculated life is bound to differ from practical results.

Table I. Typical Moon Relay System

Parameter	Value
Frequency	2,000 mc
Transmitter power	10 kw cw
Antenna size	60-ft parabolic
Antenna beamwidth	0.6 degree
Transmitter power, P_t	+40 dbw
Antenna gain, $G_t + G_r$	+100 db
Median circuit loss, L_c	−276 db
Line losses, L_L	−4 db
Median received power, C	−140 dbw
Noise figure, F	9 db
Noise power per cycle (kT)	−204 dbw
3-kc bandwidth, B	35 db
Noise power, N	−160 dbw
Median C/N	20 db
Minimum usable C/N	15 db
Fading allowance, L_F	5 db
Reliability	80% (no diversity) 99% (triple diversity)

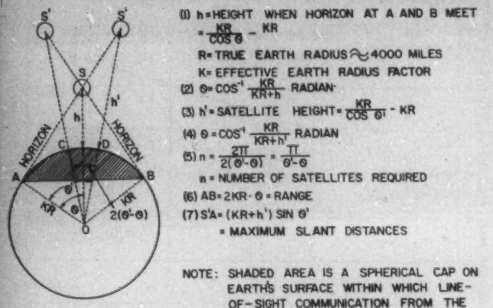


Fig. 6. Satellite relay geometry (circular equatorial orbit).

Relay Geometry. As discussed in the previous section, the most ideal conditions for relay occur when the satellite is in a circular equatorial orbit. Practically, it may be difficult to fulfill this condition, but the closer this ideal is approached, the better is the performance of the system predicted.

Fig. 6 shows the ideal relay geometry. When the satellite is at a height h, where the horizons at earth stations A and B meet, relay is impossible because the two stations can see the satellite simultaneously at one instant only. If the satellite is in orbit at a height, h', instead of h, it is seen simultaneously by the two stations through an angle $2(\theta'-\theta)$. Therefore, if there are

$$n = \frac{2\pi}{2(\theta'\theta)} = \frac{\pi}{\theta' - \theta} \text{ satellites,}$$

each satellite at an angular distance of $\theta' - \theta$ from the other, an uninterrupted relay is possible provided that the satellites are equidistant from each other in the same circular equatorial orbit. Such conditions can not be met in practice, but slight orbital deviations can be tolerated from the system performance point of view.

Based on the satellite relay geometry of Fig. 6, the relations between satellite height, number of satellites required, ranges (great-circle distance between earth stations), and maximum slant distance for uninterrupted relays are shown in Fig 7. True earth radius ($K = 1$) is used at heights of hundreds of miles or more above earth, the effect of atmospheric refraction being negligible as far as the path geometry is concerned.

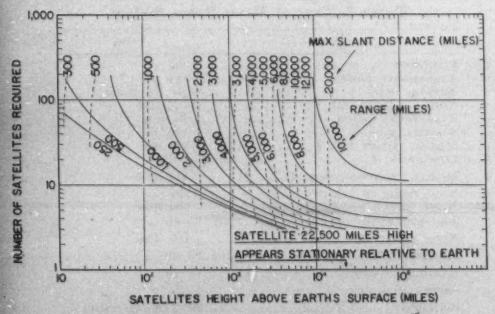


Fig. 7. Number, height, range, and slant distance of satellite.

It can be seen that the higher the satellites are in orbit, the smaller is the number required for a given range. For long ranges, the satellite must be high in orbit.

One interesting parameter is the maximum slant distance—the distance which the relay system is expected to cover. It may be several times larger or smaller than the range (the great-circle distance between the two earth stations), depending on the number of satellites used. For instance, as shown in Fig. 7, a 1,000-mile range requires a maximum slant distance of 2,000 miles with 10 satellites and 5,000 miles with 4 satellites, but only about 500 miles with 300 satellites. The smaller the number of satellites, the longer is the maximum slant distance compared to range. This puts rather stringent requirements on some of the vital parameters of the relay system, such as transmitted power and antenna sizes or gain, because of the longer distances to be covered.

A satellite relay system between two earth stations (earth-satellite-earth) is a simple 2-hop link in radio terminology. In some cases, more than one link with intermediate earth stations may be more desirable, and Fig. 7 may be used for determining the orbital requirements for such multilink systems. For example, a 1-link 1,000-mile system with 10 satellites, each 430 miles high, may be replaced by a 2-link 500-mile system with an intermediate earth station, with either 10 satellites 300 miles high or 8 satellites 430 miles high.

For uninterrupted relay, the satellite must be tracked continuously by the two earth stations. In practice, the relay is intermittently interrupted because of the time required to return the antenna to its initial position for tracking the next succeeding satellite, after the first has been tracked to its disappearance below horizon. For a large antenna, the interruption may be quite long because of the large mass involved.

Although an uninterrupted satellite relay system generally requires a large number of satellites, a few schemes may be used to reduce this number.

1. Four equidistant satellites may be placed in a circular equatorial orbit at a height of 22,500 miles (approximately 26,500 miles from the center of the earth). At this height, the satellites appear to be stationary relative to the earth and can serve as relay stations between any two locations on earth, using 1-link or multilink arrangements, depending on the range. As discussed previously, however, use of a small number of satellites considerably extends the slant distance to be covered, increasing the requirements of some of the vital system parameters.

2. The number of satellites might be reduced without changing the spacing between them, reducing the usable time accordingly. Consider the 1,000-mile range, 10-satellite system as an example. If 5 satellites were used

instead of 10 and the same spacing maintained between satellites (36 degrees of arc in this case), the relay would work half of the time.

3. Fixed (nontracking) antennas might be used. As the satellite passes over the first earth station, it receives and stores the message. As it passes over the next earth station, a command or trigger signal causes the satellite to transmit the stored message. The usable time depends on the antenna beamwidth of the earth station and is, in general, quite limited since widening the beam for more usable time decreases the gain of the antenna. In order to relay a large amount of information, therefore, a fast rate of transmission must be used. This scheme has been demonstrated recently by the United States Score Satellite, an 8,750-pound intercontinental ballistic missile (Atlas) with a 4-minute message-storage time.

System Design. Although available data are still sketchy, the radio observations of satellites indicate that the satellite signals, like moon echoes, are subject to continuous fading at both slow and fast rates. As indicated earlier, the slow fading is due to the Faraday effect. The fast fading probably results from the spinning of the satellite. Through use of higher uhf and the recently advocated satellite stabilization technique, the fading may be reduced considerably. This, however, must be confirmed by extensive experiments. In the present study, the same magnitude of moon-relay fading allowance is recommended for satellite relay.

Since the satellite is a moving object, the carrier frequency is subject to a double doppler shift for a 2-hop link. The maximum single doppler shift in cycles per second f_{ss} may be calculated by

$$f_{ss} = \frac{fV}{c} \tag{1}$$

where

f = carrier frequency in cycles per second
V = velocity of satellite relative to earth in miles per hour
c = velocity of light in miles per hour = 186,000 × 3,600

The velocity of the satellite is proportional to its height above earth's surface. For a circular path, the velocity may be expressed[17] as

$$V = R\sqrt{\frac{g}{R+h'}} \text{ mpr} = \frac{1.13 \times 10^6}{\sqrt{(4{,}000+h')}} \tag{2}$$

where

R = earth's true radius in miles = 4,000
h' = satellite height above earth's surface in miles
$g = 32.2$ ft/sec^2 = 79,000 m/hr^2

The orbital period T, the time required for the satellite to complete one orbit of the earth, may be expressed as

$$T = \frac{2\pi(R+h')}{V} \text{ hours} \tag{3}$$

combining equations 1 and 2:

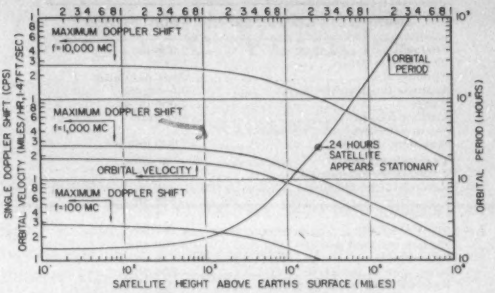


Fig. 8. Doppler shift, orbital velocity, and period.

$$f_{ss} = \frac{f}{600\,(4{,}000+h')^{\frac{1}{2}}} \text{ cps} \tag{4}$$

combining equations 2 and 3:

$$T = \text{orbital period in hours} = 5.5 \times 10^{-6}\,(4{,}000+h')^{3/2} \tag{5}$$

Satellite velocities V, single Doppler shifts f_{ss}, and orbital period T for various satellite heights are plotted in Fig 8. Both passive and active relays are feasible.

A typical active satellite relay system using a high-gain antenna on earth but an isotropic antenna in the satellite is shown in Table II. In this typical system a ½-watt transmitter is used in both the earth station and the satellite. A gain of 120 db is required in the satellite. More power at the earth station can be traded off with less gain required in the satellite.

It is interesting to note that four times (+6 db) more transmitter power and four times (+6 db) satellite repeater power gain is required if the antenna size is reduced to one-half. On the other hand, if the antenna size is doubled, both transmitter power and satellite repeater power gain can be reduced to one-quarter (−6 db).

A typical passive system with 15 satellites 460 miles high and using the same frequency, transmitter power,

Table II. Active Satellite Relay System (Two-Way)

	Earth-Satellite	Satellite-Earth
Satellite repeater gain		+121 db
Transmitter power	½ watt	½ watt (+121 − 124 = −3 dbw)
Frequency	300 mc	300 mc
Satellite antenna	isotropic	isotropic
Earth antenna (parabolic)	60 ft	60 ft
Range	2,000 miles	2,000 miles
Satellite height	460 miles	460 miles
No. of satellites	15	15
Max slant distance	2,000 miles	2,000 miles
Free space loss (L_{FS})	−153 db	−153 db
Transmitter antenna gain (G_t)	+ 33 db	0 db
Receiver antenna gain (G_r)	− 0 db	+ 33 db
Line loss (L_T)	− 1 db	− 1 db
Net transmission loss	−121 db	−121 db
Transmitted power (P_t)	− 3 dbw	− 3 dbw
Median received power (C)	−124 dbw	−124 dbw
Receiver noise figure (F)	+ 6 db	+ 6 db
Thermal noise per cycle (KT)	−204 dbw	−204 dbw
Receiver bandwith (B=3 kc)	+ 35 db	+ 35 db
Thermal noise power (N)	−163 dbw	−163 dbw
Multihop degradation	—	+ 3 db
Net noise power	−163 dbw	−160 dbw
Median C/N	39 db	36 db
Minimum usable C/N	15 db	15 db
Fading allowance	24 db	21 db
Reliability	99 +%	99 %

Table III. Passive Satellite Relay System

Frequency	2,000 mc
Transmitter power	10 kw
Antenna size	60-ft parabolic
Antenna beamwidth	0.6 degree
Range	2,000 miles
Satellite height	460 miles
No. of satellites	15
Max slant distance	2,000 miles
Transmitted power	+ 40 dbw
Transmitter antenna gain	+ 50 db
Receiver antenna gain	+ 50 db
Free space loss	−338 db
Line losses	− 4 db
Echo area gain	+ 62 db
Median received power	−140 dbw
Noise figure	+ 9 db
Noise power per cycle	−204 dbw
Receiver bandwidth (B=3 kc)	+ 35 db
Noise power	−160 dbw
Median C/N	20 db
Minimum usable C/N	15 db
Fading allowance	5 db
Reliability	80% (no diversity) 99% (triple diversity)

and antenna size as the typical moon system discussed previously is shown in Table III.

Assuming that the satellite is a sphere with an effective echo area equal to 0.5 of the projected area, then

$$10 \log_{10} \frac{4\pi A_b \times 0.5}{\lambda^2} = 62 = \text{echo area gain of satellite} \qquad (6)$$

where

A_b = projected area of satellite = πr^2
r = satellite radius
λ = wave length = 0.5 feet (at 2,000 mc)

From equation 6, a sphere 280 feet in diameter is required.

Moreover, the angles subtended by a 280-foot satellite at a distance of 2,000 miles is very small, on the order of 10^{-3} degrees, and unless its orbit can be predicted with fair accuracy, radio tracking will not be easy. Fortunately, from the experience gained in the observation of the Soviet and United States satellites, determination of satellites' orbits is no longer considered a serious problem.

CONCLUSIONS

BOTH MOON AND SATELLITE RELAYS are feasible means for the extension of global communications. In the present state of the art, moon relay seems to have some edge over satellite relay, and since the moon is free for all, moon relay may be the cheapest way to extend the range of global communication. There are, however, certain limitations that must not be overlooked.

1. While the usable time of moon relay is continuous, it is limited and varies from day to day, and depends on the locations of the earth stations and the great circle distance between them. In practice, a compromise between usable time and range must be observed.

2. It takes 2.5 seconds for a signal to take a round trip from the earth to the moon. Immediate response is, therefore, impossible.

On the other hand, it is possible for satellite relays to achieve continuous service all the time at all ranges, depending on the number of satellites used and their height. Response time, in general, is short. The difficulty seems to be the problem of putting a large number of satellites in precise orbits with a fairly long lifetime.

Both moon and satellite relays are subject to certain restrictions common to any long-distance communications, such as narrow bandwidth, small signal-to-noise ratio, and low system reliability. Therefore, intensive research and development are required on high-power r-f transmitters, high-gain antennas for both satellites and earth stations, low-noise amplifiers, bandwidth reduction, novel modulation techniques, etc.

Satellites have the advantage of being readily controllable while the moon is not. Although it may take some time before this advantage can be fully realized, the research and development of satellite relays should not be overlooked in the future planning of global communication systems despite their present limitations.

REFERENCES

1. American Ephemeris and Nautical Almanac (book). U. S. Government Printing Office, Washington, D. C., published annually.
2. The Air Almanac (book). U. S. Government Printing Office, Washington, D. C., published three times annually.
3. Navigation and Nautical Astronomy (book), B. Dutton. U. S. Naval Institute, Annapolis, Md., 10th edition, 1951.
4. Reference Data for Radio Engineers (book). International Telephone and Telegraph Corporation, New York, N. Y., 4th edition, 1956.
5. Radar Echoes from the Moon, J. Moffenson. *Electronics*, New York, N. Y., April 1946, pp. 92-98.
6. Reflection of Microwaves from the Moon, Z. Bay. *Hungaria Acta Physica*, Budapest, Hungary, vol. 1, 1946, pp. 1-22.
7. Moon Echoes and Penetration of the Ionosphere, E. J. Kerr, et al. *Nature*, Washington, D. C., Feb. 26, 1949, pp. 310-13.
8. Moon Echoes and Transmission Through the Ionosphere, E. J. Kerr, et al. *Proceedings*, Institute of Radio Engineers, New York, N. Y., March 1951, pp. 230-42.
9. Radio Echoes from the Moon, Browne, et al. *Proceedings*, Physical Society, London, England, Sept. 1956, pp. 901-20.
10. Detection of Radio Signals Reflected from the Moon, J. H. Dewitt, E. K. Stodola. *Proceedings*, Institute of Radio Engineers, March 1949, pp. 229-42.
11. A UHF Moon-Relay, P. G. Sulzer, et al. *Ibid.*, March 1952, pp. 361.
12. UHF Moon Reflections, Fricker, et al. International Radio Scientific Union, Washington, D. C., April 24-26, 1958.
13. Considerations of Moon-Relay Communication, D. D. Grieg, et al. *Proceedings*, Institute of Radio Engineers, May 1948, pp. 652-63.
14. Lunar Radio Echoes, J. H. Trexler. *Ibid.*, Jan. 1958, pp. 286-92.
15. Radar Echoes from the Moon at a Wavelength of 10 Cm. Yaplee et al. *Ibid.*, pp. 293-97.
16. Introduction to Space Communication System Design, L. P. Yeh. *Electronic Industries*, Philadelphia, Pa., Feb.-March 1959.
17. The Physical and Chemical Fundamentals of Satellite Flight—Part II, P. F. Winterwitz. *Journal of Astronautics*, New York, N. Y., vol. 3, nos. 3-4, Autumn-Winter, 1956, p. 65.
18. Satellite Ascent Guidance Requirements, J. Jensen. *Ibid.*, vol. 3, no. 1, Spring 1956, p. 1.
19. Problem of Launching an Earth Satellite, M. Summerfield. *Astronautics*, New York, N. Y., Nov. 1957, p. 18.
20. Lifetimes of Satellites from Near-Circular and Elliptic Orbits, N. V. Petersen. *Jet Propulsion*, New York, N. Y., May, 1956.

Wear Your

AIEE Badge

Radiation Shielding for Space Vehicles

J. W. KELLER

N. M. SCHAEFFER

A study is being conducted of problems in shielding manned vehicles from previously unknown radiations in space. Two areas of the radiation problem—Van Allen radiation and solar protons—are of major concern in this study.

DISCOVERY and subsequent investigation of previously unknown radiations in space have generated extreme interest in the ramifications of these phenomena on manned space missions. The effects of these radiations may overshadow those of the normal cosmic background by as much as a factor of 10^3. Of course, the principal consideration is the biological hazard, since intensities corresponding to exposure dose rates up to several hundred roentgens per hour have been observed. These intensities, although small from the standpoint of thresholds for radiation damage to materials (the lowest are 10^5 to 10^6 rem*), are large compared to generally accepted permissible whole-body exposures (5 rem per year, 25 rem one-time exposure).

Therefore, a thorough investigation of the nature and distribution of these radiations and methods for attenuating them to acceptable levels must be executed as a part of our space program. Under contract to the National Aeronautics and Space Administration, Convair is conducting a study of the problem of shielding manned vehicles from these radiations.

This article contains a description of the radiation, a survey of potential shield materials, an evaluation of charged particle transmission through these materials, and some implications on vehicle design in terms of shield weights.

DESCRIPTION OF RADIATION

TWO AREAS of the radiation problem—Van Allen radiation and solar protons—are of major concern in this study. Van Allen radiation consists of charged particles trapped in the earth's magnetic field forming two broad belts which extend in a doughnut fashion around the earth equatorially, while solar protons identify the large numbers of high-energy particles which are observed to reach the vicinity of the earth following large solar flares.

Fig. 1 shows the apparent spatial distribution and particle identification of the Van Allen radiation and peak intensities of a typical solar proton outburst. The spatial distribution of the Van Allen belts given in the figure is based both on measurements and theory, and reflects the belts as they existed at the launching of Pioneer III. The intensity values are estimates made by Van Allen.[1] Although the inner belt has been seen to remain essentially unchanged during the entire period of observation, the outer belt has been seen to vary as much as a factor of 10 in intensity and as much as 50,000 kilometers in extent into space.

The intensity value given for solar protons is the peak measured intensity for a typical event (May 10, 1959) and was obtained from high-altitude balloon measurements made at the University of Minnesota. The measurements indicate the particles may be isotropic when they reach the vicinity of the earth. Increased proton fluxes are observed to persist as long as 12 days following a flare; however, maximum intensities prevail for only about 1 day.[2] Unlike Van Allen radiation, solar protons are not confined to specific regions of space, but presumably extend throughout the solar system. Flares resulting in solar proton outbursts are being detected with a frequency of about 10 per year at this time. The dependence of these outbursts on other solar cycles is unknown. Similarly, the accompaniment of the protons by low-energy electrons is not well resolved.

SHIELDING MATERIALS

SHIELD WEIGHT is obviously the most important single factor in determining the best shield materials for manned space vehicles. Since electrons of the energies expected to be encountered in space are much less penetrating than the protons in the inner Van Allen belt and in solar proton outbursts, the proton shielding is, for the most part, the determining quantity so far as weight is concerned.

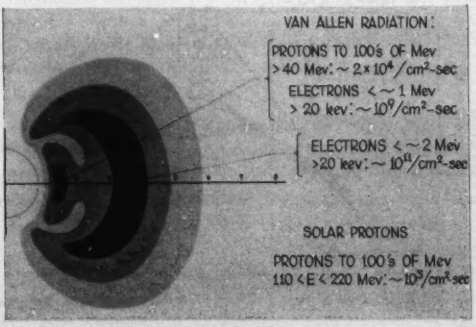

VAN ALLEN RADIATION:
PROTONS TO 100's OF Mev
>40 Mev: ~ 2 × 10⁴/cm²-sec
ELECTRONS < ~ 1 Mev
> 20 kev: ~ 10⁹/cm²-sec
ELECTRONS < ~ 2 Mev
>20 kev: ~ 10¹¹/cm²-sec
SOLAR PROTONS
PROTONS TO 100's OF Mev
110 < E < 220 Mev: ~ 10³/cm²-sec

Fig. 1. Space radiations.

Full text of conference paper CP60-991, presented at the AIEE Pacific General Meeting, San Diego, Calif., Aug. 8-12, 1960. Recommended for publication by the AIEE Aero-Space Transportation Committee.

J. W. Keller, formerly with Convair, a Division of General Dynamics Corporation, Fort Worth, Texas, is now with the Marshall Space Flight Center, Huntsville, Ala.; N. M. Schaeffer is with Convair, Fort Worth, Tex.

*The rem (roentgen equivalent, man) is a unit of dose equal to relative biological effectiveness × absorbed dose in rads.

Plots of proton range data[3] in grams per square centimeter vs. atomic number for the elements display a minimum at an atomic number $Z = 6$, or carbon. Hydrogen, however, lies well off the continuous curve, being far superior to any other element on this basis. Since the shielding of a space vehicle crew compartment will involve enclosing a rather large volume within a shield, it is more practical to compare shield materials on the basis of weights of spherical shells of the required thickness. Such comparisons have been made for a wide range of materials for various values of the inside radius. Plots for an inside radius of 4 feet are shown in Fig. 2. Here, the weight of the spherical shield is plotted vs. the proton energy which will just penetrate the shield. It is seen that for thin shields hydrogenous materials are superior. However, for the thicker shields carbon is best, the hydrogenous materials becoming less effective (on a weight basis) because of geometrical considerations as a result of their low densities.

Weight of the shield system itself is not the only consideration necessary in selecting the best shielding materials. Constraints must be placed on the dimensions of the shield system, since it is only one part of an integrated vehicle. Fig. 3 is a plot of the outside radius vs. the proton energy threshold for the same materials considered in the preceding figure. It is again seen that hydrogenous materials are less practical for thicker shields and that liquid hydrogen, by itself, is practical only for very thin shields. Carbon, on the other hand, which was seen to be a promising material from a weight standpoint, is seen to be quite satisfactory on this basis as well. For these reasons, plus the facts that its yield of secondary neutrons under proton bombardment is relatively small and that it has a possible dual use as a heat shield, carbon was chosen as the shield material for this study.

SHIELDING EFFECTIVENESS

Van Allen Protons. Calculations have been made to determine the proton dose rate as a function of carbon shield thickness in the heart of the inner Van Allen belt. The calculations were made for a slab geometry with the estimated total omnidirectional flux being considered to be incident normally on the slab. The calculations, which considered both the reduction of particle energy through ionization losses and the attenuation of the particle beam as a result of nuclear reactions, were made using the equation

$$\text{Dose} = K\int_{E(t)}^{700} S(E')\,R(E')\exp\left[-\frac{E}{120}-\int_0^t \Sigma_r(E_x)dx\right]dE$$

where

t = slab thickness

$\exp(-E/120)$ = the slope of the proton spectrum as measured by Freden and White[4]

E_x = the energy (after penetrating a distance x into the slab) of a proton having incident energy E

$\Sigma_r(E_x)$ = nuclear reaction cross section in carbon for a proton of energy E_x

E' = energy (after penetrating the slab) of proton with incident energy E

$S(E')$ = specific ionization in tissue of a proton of energy E'

$R(E')$ = RBE (relative biological effectiveness) for proton of energy E' (1 for $E' > 40$ mev (megelectron-volts); 2 for $E' < 40$ mev)

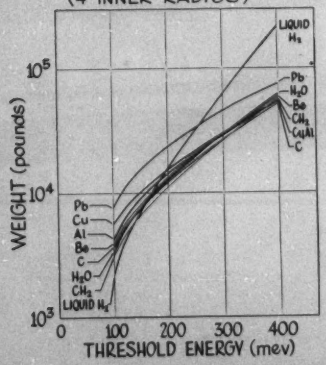
$E(t)$ = energy of proton whose range is just t

K = constant which includes conversion factors and normalization of spectrum to measured intensities

Considering the radiation to be isotropic, the results of this calculation would be approximately equivalent to that for the center point within a spherical shield of the same thickness.

The largest dose rate contribution from secondary radiation originating from nuclear reactions within the shield would be from neutrons emitted in (p,xn) reactions. Rough calculations have been made to determine the significance of this component. Since the results were to be applied to the case of a spherical shield all the energy released from the reactions was considered to be carried by neutrons directed in the forward direction to compensate for contributions, in the actual case, from reactions of protons not having normal incidence. The same RBE was used for neutrons as that given for protons.

The results of these calculations, along with the incident proton spectrum, are shown in Fig. 4. The spec-



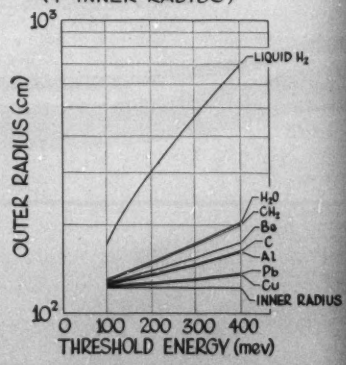


Fig. 2 (left). Spherical shield weight vs. threshold energy. Fig. 3 (right). Outer shield radius vs. threshold energy.

trum was determined by Freden and White[5] from nuclear emulsions exposed in the inner portions of the belt during the flight of a Thor-Able ballistic vehicle in which they measured proton energies up to 700 mev. These results indicate the contribution from secondary neutrons will be significant in case of thick shields.

Van Allen Electrons. Since electrons of the energies involved in the Van Allen belts are quite easily stopped, they present a significant problem only through the production of bremsstrahlung (gamma rays). Although the gamma rays are of low energy (for the most part much less than the electron energies), their flux is so high that they must be evaluated.

Calculations have been made to determine the dose rate at the center of a spherical volume surrounded by a carbon shield as a function of shield thickness in the heart of the outer Van Allen belt considering two groups of monoenergetic electrons based on rough estimates of the electron spectrum by Van Allen. The average amount of energy radiated as bremsstrahlung when electrons of less than a few mev are stopped in a thick target of atomic number Z is given by ωE, where E is the energy of the incident electron in mev and ω is given by[5]

$$\omega = \frac{1.98 \times 10^{-4}\,[1.96E + 2]}{[1 + 0.35 \log_{10}(82/Z)]}\,Z$$

The spectral distribution of the emitted gamma rays is given by[6]

$$I(E_\gamma) = \text{const}\left[4\left(1 - \frac{E_\gamma}{E}\right) - 3\,\frac{E_\gamma}{E}\ln\left(\frac{E}{E_\gamma}\right)\right]$$

For the calculations, this equation was normalized to the energy determined in the preceding equation. Since the electrons are stopped in the first few tenths of a centimeter of the shield, the bremsstrahlung was assumed to originate at the shield surface. Assuming the incident electrons to be isotropic and the resulting bremsstrahlung to be isotropic over the forward hemisphere at each point on the shield surface results in the calculations being independent of the inner radius of the shield with the dose being determined from the equation

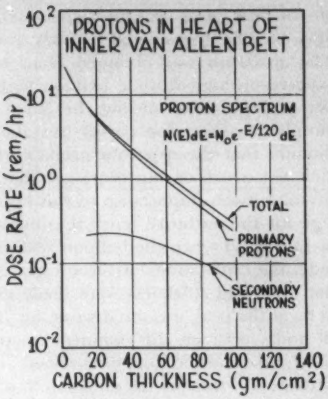
$$\text{Dose} = \frac{S_o}{4\pi}\int_0^{E_{\gamma\max}}\int_0^{2\pi}\int_0^{\pi}\frac{I(E_\gamma)\,B(E_\gamma)}{f(E_\gamma)}\exp(-\mu_c t_c)\sin\Theta\,d\Theta\,d\phi\,dE_\gamma$$

$$= S_o\int_0^{E_{\gamma\max}}\frac{I(E_\gamma)B\,(E_\gamma,\mu_c t_c)}{f(E_\gamma)}\exp(-\mu_c t_c)dE_\gamma$$

where

S_o = omnidirectional electron flux
$(\mu_c t_c)$ = number of mean free paths for gammas of energy E_γ in carbon thickness t_c
$B(E_\gamma,\mu_c t_c)$ = dose buildup factor for gammas of energy E_γ penetrating a thickness t_c of carbon
$f(E_\gamma)$ = flux-to-dose conversion factor for gammas of energy E_γ

Fig. 4. Dose rate vs. carbon shield thickness.



While carbon is a good shield from the viewpoint of relatively small bremsstrahlung production (bremsstrahlung production increases with increasing atomic number), it does not offer much attenuation to the gamma rays which are produced. As a result, the calculated dose rates were found to be quite high. Calculations have been made to determine the effect of placing lead layers of different thicknesses on the inner surface of the shield. For these calculations, the equation was modified as follows:

$$\text{Dose} = S_o\int_0^{E_{\gamma\max}}\frac{I(E_\gamma)B(E_\gamma,\mu_c t_c,\mu_{pb}t_{pb})}{f(E_\gamma)}\exp(-\mu_c t_c - \mu_{pb}t_{pb})dE_\gamma$$

Here, the multilayer buildup factors were determined from the equation of Kalos.[6]

The results of the calculations for the outer belt electrons are shown in Fig. 5, along with the rough estimate of the spectrum after Van Allen.[1]

That a significant reduction in dose rate may be obtained by the addition of a thin layer of lead on the inner shield surface is illustrated by the lower two curves in the figure. The addition of a 0.25-centimeter layer to a 4-foot inner radius carbon shield results in a weight increase of only about 0.8% in a shield designed to stop 400-mev protons (90 grams per square centimeter) or about 8% in a shield for 200-mev protons (28.5 grams per square centimeter).

Approximate dose rate values for the inner belt electrons may be obtained by dividing the results in Fig. 5 by 10^2.

Solar Protons. Calculations of the same type described earlier for the Van Allen belt protons have been made for the primary solar protons using the equation

$$\text{Dose} = K'\int_{E(t)}^{220} S(E')\,R(E')\,E^{-4.8}\exp\left[-\int_0^t\sum_r(E_x)dx\right]dE$$

where $E^{-4.8}$ is the measured spectral shape, K' a normalization constant, and the other symbols as defined for the previous proton calculation. Calculations of secondary components for this case have not been carried

out. The results of the calculations, which were based on the peak measured intensities following the flare of May 10, 1959 (considered typical), are shown in Fig. 6. The spectrum was obtained from nuclear emulsions exposed on high-altitude balloon flights at the University of Minnesota[2] during the flare. Although the atmospheric absorption cut-off was about 110 mev, it is thought that the spectrum probably holds to 20 to 30 mev. Since such outbursts are not continuous, the quantity of greatest importance in this case is the integrated dose for the outburst. Since the intensity was found to be falling off when the balloon reached maximum altitude, the calculations of the integrated dose as a function of shield thickness were made assuming the flare to be at the peak measured value for the approximately 29 hours between the commencement of cosmic noise absorption and the time the balloon attained maximum altitude and then to fall off at the rate measured by the balloon (exp $0.575t$). The results of these calculations are shown in Fig. 7.

In addition to the type of solar proton outbursts just considered, outbursts of protons having energies in the bev (billion-electron-volt) range have been observed. Of course, these outbursts, which are of high enough intensity to be detected at sea level, will pose a much more severe problem, upon occurrence, than do flares of the type considered above. Fortunately, they do not occur with the same frequency as the lower-energy outbursts. Only five such events have been observed over the last 20 years.[6]

SHIELD REQUIREMENTS

THE RESULTS of the calculations described previously are combined in Fig. 8 for easy comparison.

Let us consider a vehicle orbiting in the heart of the inner Van Allen belt. We will consider a spherical crew compartment having a 4-foot inner radius for this case and subsequent cases to be discussed later. We see that the problem in this region is indeed severe, possibly rendering this region useless for manned orbiting missions for some time. An idea of the severity of the problem may be derived from the fact that 45,000 pounds of shielding only reduces the dose rate from primary protons alone to about 0.5 rem per hour. It must be remembered that this value is only for the heart of the belt and that the problem would be less severe elsewhere in the region.

For a vehicle orbiting in the outer Van Allen belt with a carbon shield, the bremsstrahlung from the stopping of electrons is seen to be the major consideration. However, if a shell of lead 0.25 centimeter thick is placed on the inner shield surface, the solar proton problem becomes of major importance. The problem in this region is not so severe as that in the region of the inner belt. About 10,000 pounds of shielding (with lead backing) reduces the dose rate from bremsstrahlung to about 0.4 rem per hour (10 rem per day) and the integrated dose from a typical solar flare to about 10 rem, most of which would be absorbed in a one-day period. Again, the bremsstrahlung figure is for the estimated peak intensity in the region, while the dose from the solar outburst would apparently be independent of the position in the belt. These flares, as pointed out earlier, are being observed to occur at the rate of about 10 a year.

The astronaut whose mission is to be carried far beyond the Van Allen belts will probably be able to traverse the region of Van Allen radiation rapidly enough so that the controlling factor in his shielding will be solar protons. The dose received with rapid traversal of the Van Allen belts as well as the effect of variations in the outer belt may be illustrated by the space probe shots Pioneer III and Pioneer IV. The results of the foregoing dose rate calculations have been used along with the radiation intensity measurements[1] made by these vehicles to determine the dose rate as a function of time for a vehicle shielded by 5 grams per square centimeter of carbon traveling the same trajectories. These plots along with the integrated doses are shown in Fig. 9 for the cases with and without a 0.25-centimeter lead layer on the inner shield surface. While these doses would probably be tolerable, this amount of shielding is well under that required for protection from solar protons. As pointed out above, a shield

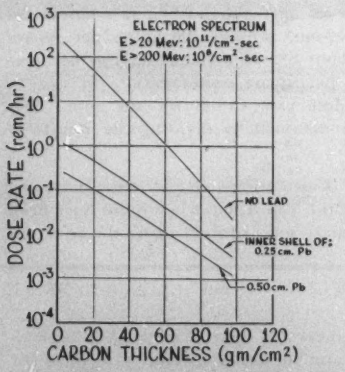


Fig. 5. Dose rate vs. carbon shield thickness (electrons in heart of outer Van Allen belt).

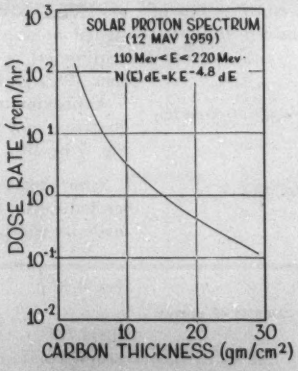


Fig. 6. Dose rate vs. carbon shield thickness (peak for "typical" solar flare).

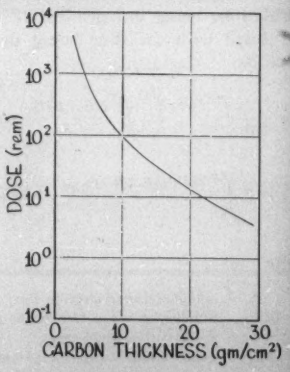
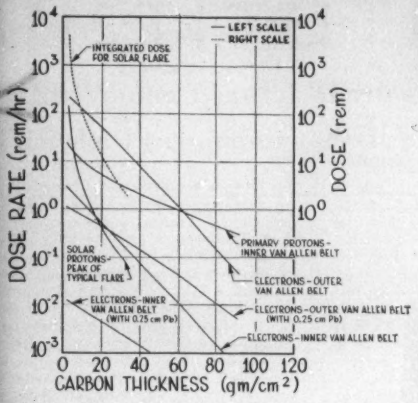


Fig. 7. Integrated dose vs. carbon shield thickness ("typical" solar flare).


LEFT SCALE
RIGHT SCALE
INTEGRATED DOSE FOR SOLAR FLARE
SOLAR PROTONS - PEAK OF TYPICAL FLARE
PRIMARY PROTONS - INNER VAN ALLEN BELT
ELECTRONS - OUTER VAN ALLEN BELT
ELECTRONS - INNER VAN ALLEN BELT (WITH 0.25 cm Pb)
ELECTRONS - OUTER VAN ALLEN BELT (WITH 0.25 cm Pb)
ELECTRONS - INNER VAN ALLEN BELT
DOSE RATE (rem/hr)
DOSE (rem)
CARBON THICKNESS (gm/cm²)

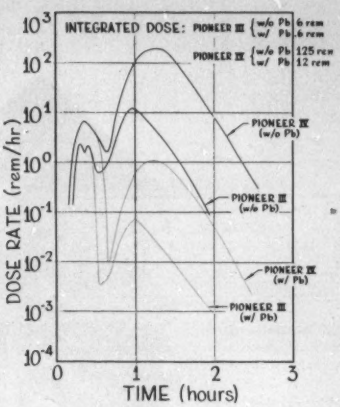

INTEGRATED DOSE: PIONEER III (w/o Pb 6 rem, w/ Pb 6 rem)
PIONEER IV (w/o Pb 125 rem, w/ Pb 12 rem)
PIONEER IV (w/o Pb)
PIONEER III (w/o Pb)
PIONEER IV (w/ Pb)
PIONEER III (w/ Pb)
DOSE RATE (rem/hr)
TIME (hours)

Fig. 8 (*left*). Carbon shielding effectiveness. Fig. 9 (*right*) Dose rate vs. time. (Pioneers III and IV trajectories behind 5 gram per cm² carbon).

weight of about 10,000 pounds (22 grams per square centimeter) would be needed to reduce the integrated dose for the "typical" flare to about 10 rem, most of which would be received in a one-day period.

It must be pointed out that the values given are based on present best estimates of the radiation environment and are subject to change as more and more data become available. Also, several approximations and assumptions are involved in the calculations, which will be improved in the future. Consequently, the results given in this article are not meant to be definitive, but are intended only as estimates. No attempt has been made at this point to consider the problem of integrating the shield system into a vehicle with a particular mission; more complete radiation data must be obtained before such definitive work can be accomplished. It is obvious, however, from the present calculations that since the weight penalty for shielding is severe, every effort must be made to reduce the weight of the shield.

Because of its spatial limitation to the vicinity of the earth (and other planets with magnetic fields), it is evident that the Van Allen radiation is a serious problem only for manned orbital missions which must operate within the bands. The impact of solar protons on space missions is obviously more severe and may be a limiting factor on long-endurance trips to the planets. This fact, along with the fact that the solar proton outbursts are intermittent in nature, suggests that a possible weight advantage could be realized by using two crew compartments. One of the compartments would be a large compartment for normal operations and the other a much smaller, heavily shielded compartment for occupancy for a short time following large solar flares. Such an arrangement is illustrated in Fig. 10 (a).

Another possible advantage of this type of configuration is illustrated in Fig. 10 (b). In this case, the shielding for the small compartment is utilized as a shadow shield for protection of the large compartment from radiation originating from a nuclear auxiliary power unit. The reactor power could be cut following a solar flare, making chamber occupancy safe.

Another variation is to mount the nuclear power unit on a collapsible beam arrangement, enabling the unit to be extended a distance behind the vehicle, making maximum use of the r^2 effect in shielding against the reactor. This would make possible the use of the small compartment without the reduction of reactor power.

The use of a liquid material for the proton shield would allow the shielding to be moved about so as to surround either compartment, making it possible to place a shield of less thickness about the larger compartment. Such an arrangement would reduce the length of the required stay in the small compartment. It is felt that an arrangement of the general type suggested should be considered in the design of future long-range space vehicles.

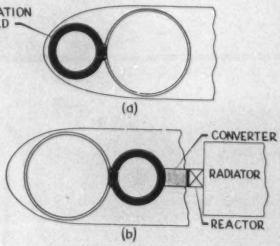


Fig. 10. Possible shield arrangements.

REFERENCES

1. Radiation Measurements to 658,300 Kilometers with Pioneer IV, J. A. Van Allen, L. A. Frank. *Report SUI-59-18*, State University of Iowa, Iowa City, Iowa, Aug. 1959.

2. Protons from the Sun on May 12, 1959, E. P. Ney, J. R. Winckler, P. S. Freier. *Physical Review Letters*, New York, N. Y., vol. 3, 1959, pp. 183-85.

3. Range Energy Tables, M. Rich, R. Madey. *Report UCRL-2301*, Lawrence Radiation Laboratory, University of California, Livermore, Calif., Mar. 1954.

4. Protons in the Earth's Magnetic Field, S. C. Freden, R. S. White. *Report UCRL-5581-T*, Lawrence Radiation Laboratory, May 1959.

5. Radiation Shielding (book), B. T. Price, C. C. Horton, K. T. Spinney. Pergamon Press, New York, N. Y., 1957.

6. A Monte Carlo Calculation of the Transport of Gamma Rays, M. H. Kalos. *Report NDA-56-7*, Nuclear Development Corporation of America, White Plains, N. Y., July 1956.

HEY, DADDY, YOU'RE AN ENGINEER—WHAT ARE YOU DOING TO HELP BUILD IT?

INSTITUTE ACTIVITIES

AIEE Winter General Meeting To Take Place January 29-February 3

THE AIEE Winter General Meeting will be held January 29-February 3, 1961. Because of the large number of technical sessions covering all six technical divisions of the Institute, meetings will take place in both the Statler-Hilton and the Governor Clinton Hotels, New York, N. Y. As usual, the Statler-Hilton will be headquarters for the meeting.

About 116 sessions are being organized. It is expected that approximately 600 Transactions and Conference Papers will be presented.

Informal Tea

This social gathering before the formal program begins has been enjoyed by more and more persons each year. This year, the informal tea will be held Sunday afternoon, January 29, at 4-6 p.m. in the Ballroom of the Statler. There will be no charge.

From 2 p.m., the registration facilities will be open for those who wish to avoid the Monday morning rush.

Hotel Reservations

Blocks of rooms have been set aside at both convention hotels, the Statler-Hilton and Governor Clinton Hotels, for members and guests attending the meeting. Letters of request for reservations should be sent to the hotel of your choice, specifically referring to the AIEE meeting. Please do not write to more than one hotel. If your request cannot be filled, the hotel will automatically refer your request to the Hotel Accommodations Committee whose duty it is to obtain a similar reservation at another nearby hotel. The hotel will confirm directly to you.

Because of the crowded conditions in New York hotels, it is suggested that your reservation be made for arrival on Sunday, January 29, 1961, thereby avoiding delays in registration or unavailability of rooms in the early morning of subsequent days.

Rooms have been allotted for our use by the following hotels at the daily rates indicated:

Statler-Hilton Hotel (meeting headquarters), 7th Ave., 32nd to 33rd Sts.

Single Room	$ 8 to $15
Double Room	11 to 20
Twin Bedroom	15 to 25

Hotel Governor Clinton (also used for meetings) 7th Ave., 31st St.

Single Room	$ 8 to $14
Double Room	10 to 16
Twin Bedroom	12 to 18

All rooms have private bath and the rates quoted are subject to a 5% New York City hotel room tax.

Smoker

One of the social highlights of the Winter General Meeting will be the Smoker on Tuesday evening, January 31, in the Grand Ballroom of the Hotel Statler. Here will be found good food, good fellowship, and top quality entertainment.

Requests for tickets should be sent in at an early date. The price of the ticket will be $11.50 and requests should be addressed to the "AIEE Smoker Committee" at 33 W. 39th St., New York 18, N. Y., and accompanied by checks made payable to "Special Account, Secretary, AIEE."

Dinner-Dance

The Dinner-Dance will be held Thursday evening, February 2, in the Hotel Statler. Dress will be formal. Write soon for reservations for tables for 10. The price this year is $14 per ticket and requests should be sent to "AIEE Dinner-Dance Committee" at 33 W. 39th St., New York 18, N. Y., accompanied by checks made payable to "Special Account, Secretary, AIEE."

Inspection Trips

A program of inspection trips is presently being prepared which will include many of the more popular trips scheduled in prior years, as well as others that have not been available previously. Included in the schedule are trips to: Bell Telephone Laboratories; Brookhaven National Laboratories; Consolidated Edison Company's Astoria Generating Station and Indian Point Generating Station; Holophane Light and Vision Institute; International Business Machines Corporation; New York Times; New York Transit Authority Bus Maintenance Center; Radio City Music Hall; Rambusch Decorating Company; Sikorski Aircraft Division of United Aircraft Corporation; and the United Nations General Assembly. Arrangements are also being made for a Wall Street tour, as well as trips to a color television studio, a research center, and a steamship.

As in the past, advance registration will be expected for selected tours.

Ladies Entertainment

The Ladies Entertainment Committee has arranged an interesting week for ladies attending the Winter General Meeting.

The ladies schedule for the week follows:

A coffee hour will be held each morning. On Monday, a tea will be given under the sponsorship of the Phelps-Dodge Corporation. A luncheon with flower arranging demonstration at the "Top of the Sixties" will be held on Tuesday. This will be followed by a dinner with entertainment at the Penn Top of Hotel Statler. Complimentary cocktails will be served. A tour to a point of interest is on the program for Wednesday. Thursday breakfast will be held at Altman's, and at noon a luncheon and fashion show at the Ambassador Hotel. The coffee hour on Friday will end the week's entertainment.

Winter General Meeting Committee

Members of the 1961 Winter General Meeting Committee are: R. W. Gillette, chairman; W. G. Vieth, vice-chairman; J. J. Anderson, secretary; R. T. Weil, Jr., AIEE vice-president for District 3 and budget co-ordinator; D. E. Trucksess, representative, Technical Operations Department; C. F. Savage, public relations; R. M. Franklin, general session; M. Lennig, hotel accommodations; F. P. West, registration; W. McConnachie, inspection trips; T. W. Bartlett, monitors; J. G. Derse, smoker; J. E. Bevan, dinner-dance; and Mrs. H. E. Martin, ladies events.

Fall Meeting Activities Include Technical Sessions and Awarding of Medals

REGISTRATION for the 1960 AIEE Fall General Meeting, held October 9-14 at Chicago's Morrison Hotel exceeded 1,800. The meeting was again held concurrently with the National Electronics Conference, of which AIEE is co-sponsor, at the Sherman Hotel.

Inspection trips were made to the Acme Steel Company, Cook Technological Center, Commonwealth Edison Company, Illinois Bell System, the Argonne Research Reactor CP-5, the Chicago Sun Times Building, and Motorola, Inc.

Social activities included a reception tea and hospitality hour on Sunday afternoon, October 9, and the "Fall Frolics," on Wednesday, October 12. Among the activities for the ladies were a trip to the Old Orchard Shopping Center, a fashion brunch at the Morrison Hotel's Carousel Room, and a luncheon at the Chicago Athletic Club.

Awards Made at General Session

At the general session, held Monday afternoon, October 10, five important awards were made.

Dr. Ernst Weber, president of Polytechnic Institute of Brooklyn, was awarded the AIEE's Medal in Electrical Engineering Education. He was cited "for excellence as a teacher in science and electrical engineering, for creative contributions in research and development, for broad professional and administrative leadership, and in all for a considerate approach to human relations."

Prof. Perry Borden, electrical engineering department, University of Dayton, received the Morris E. Leeds Award, "for outstanding contributions to electrical measurements in the field of recording, control, and telemetry; and helpful encouragement to younger colleagues."

Dr. S. B. Crary, system analysis engineer, Electric Utility Engineering Section, General Electric Company, was given the William M. Habirshaw Award. He was cited "for contributions to the stability, reliability, and economy of bulk power transmission systems, and international leadership in this field." Charles Concordia of General Electric accepted the award for Dr. Crary.

Rudolf Kompfner, director of radio and electronics research, Bell Telephone Laboratories, Inc., was presented with the David Sarnoff Award, "for creative achievements in research and development in the field of electronics and for his leadership in this field."

The fifth engineer to be honored was Dr. M. J. Kelly, retired chairman of the board of Bell Telephone Laboratories, Inc., recipient of the first Mervin J. Kelly Award. Since Dr. Kelly was unable to attend the meeting because of duties abroad, he will receive the award at the Institute's Winter General Meeting in New York, January 29-February 3, 1961. He has been cited "for outstanding contributions in the technology of telecommunications; as a distinguished organizer and an eminent leader."

Dr. Ernst Weber Is Keynote Speaker

The keynote speech was by Dr. Weber, who chose for his topic "Profession, Society, and Engineering Education." He referred to the engineer as "the prime mover in modern civilization," who should receive credit for "creating the modern setting of society." To assure recognition of the individual engineer by increased social, political, and community responsibility, broader education of the engineer is necessary. We must devote at least one quarter of the engineering student's bachelor's curriculum to "an intensified, integrated program" that "gives the evolution of mankind in broad strokes."

That the engineer has not found adequate expression in political life, in community affairs, and in the social structure of society has been the fault not only of the members of the profession, who are generally preoccupied with their professional activities, but also of engineering education, which too readily sacrifices "the so-called humanities content of curricula to the seemingly more important technological stem."

Also presented was a brief address by AIEE President C. H. Linder, who discussed some of the problems and challenges facing the engineering societies. One of the chief problems, he stated, is that the interchange of technical information is becoming more difficult, inasmuch as the engineering societies are organized along lines which are often no longer applicable. He stressed the need for the societies to work together in order that the management function may be effective. As examples of the progress made in recent years toward this goal of unity, he pointed out the Functional Plan, introduced several years ago, as well as the United Engineering Center, now nearing completion in New York City.

Technical Sessions Held

Summaries of the technical sessions held at the conference follow:

Linear Control Systems. At a Monday morning session sponsored by the Feedback Control Systems Committee, three papers were presented. A paper by F. E. Liethen, U. S. Air Force, and C. H. Houpis and J. J. D'Azzo, both of the Air Force Institute of Technology, describes an automatic root-locus plotter which uses an analog computer. The method, utilizing an analog computer with servo resolvers, gives an accurate plot of each branch of the locus. The open-loop poles and zeros are set into the computer arrangement by means of individual potentiometers, thus giving flexibility in changing the poles and zeros to represent any system.

A new method of direct synthesis of a series compensator for a linear feedback control system was described by Franco Mariotti, Hewlett-Packard Company. This method allows the designer to satisfy simultaneously specifications on the location of the complex closed-loop poles and on steady-state behavior, taking into account constraints on the open-loop pole and zero configurations.

A simple and rapid geometrical method for solving the response problems in electric motors and similar nonlinear devices was described by J. Mori of the Case Institute of Technology

Supervisory Systems. E. W. Head, Control Corporation, Minneapolis, Minn., opened the session with a paper on the design and application of digital telemetering systems in industry. In addition to meeting the requirements for transmission of digital information, these systems also lend themselves to transmission of analog information, as well as alarm or status details.

A new type of supervising system, using switching-type solid-state logic circuits in place of conventional electromechanical relays, was described in a paper by G. E. Guy and P. W. Schirmer, both of the General Electric Company. Advantages include longer life, less weight, smaller size, lower power requirements, and greater reliability. Since the system is compatible with the all-relay type of equipment, future stations of the new design may be added to existing systems without making obsolete the equipment now in operation.

The Laurel Pipeline, extending from Philadelphia, Pa., to Cleveland, Ohio, has made extensive use of supervising, telemetering, and automation techniques, as reported in a paper by K. E. Willson, Laurel Pipeline Company, and H. N. Hickok, P. D. Woodruff, and P. W. Schirmer, General Electric Company. One of the more significant features of this petroleum products pipeline is the fact that 18 delivery points and one pumping station can be controlled from a central dispatcher's control room.

Insulated Conductors. The increasing importance of weight and cost considerations has made the need for an accurate, reliable, and easily used method determining wire ratings a necessity. Presently used current ratings are unduly conservative because of the large safety factors that are included. Such a method was presented in the paper by R. W. Stineman and G. W. McIntyre of Boeing Airplane Company, Seattle, Wash., entitled "Calculation of Steady-State and Transient Ratings of Electric Wire." This method must meet the following requirements: (1) It must be useful for any ambient condition or any installation; (2) It must be useful for steady-state or transient conditions; (3) It may be used for single wires or bundles; (4) It may be used for either direct current or alternating current; (5) It must have flexibility in the time-temperature domain; and (6) It must be directly usable and must yield easily understood results. A method of calculation utilizing basic material properties was developed. Essentially what has been done is to utilize well-known principles of heat transfer, electric phenomena, and mathematics arranged in such a manner that a computer can perform the many calculations necessary to predict a wire rating under any particular conditions. Predictions of the computer program have been verified by laboratory test.

The problem of improving lead sheathed cable was discussed in a companion paper by S. F. Radtke, C. J. Snyder, and C. C. Childress. This problem has two aspects: (1) to find better alloys and alternate lead materials for such uses; and (2) to develop a continuous extrusion machine capable of working existing higher alloys of lead. The description of such a machine of the vertical type is the main topic of the paper which is entitled "Development of a Continuous Extrusion Machine for Sheathing Cable with Lead Alloys."

Protective Devices. At the present time, permissible temperature limits for neutral grounding devices are those established in the Standard for Neutral Grounding Devices, AIEE no. 32, May 1947. These standards have been useful, but in the light of new knowledge on the thermal aging of insulation, it has seemed appropriate to review the basis for establishing these limits and where indicated, revise the old values in line with present-day thinking. J. C. Russ, of General Electric Company, in his paper "Thermal Ratings and Temperature Limits for Neutral Grounding Devices," presents the proposals of the "AIEE Working Group on the Revision of Standard no. 32." The improvements and refinements in the determination of short-circuit temperature limits which have come out of this study should, if adopted, permit the designer of neutral grounding devices considerably

AWARDED the AIEE's Medal in Electrical Engineering Education *(photo at left)*, **Dr. Ernst Weber** *(right)*, **president of Polytechnic Institute of Brooklyn, is congratulated by AIEE President C. H. Linder. Director of radio and electronics research, Bell Telephone Laboratories, Rudolf Kompfner** *(right photo, at right)* **was presented with the David Sarnoff Award by President Linder.**

more freedom than he has had heretofore to take full advantage of design characteristics which affect the thermal aging of winding insulation.

Topics also discussed were "Lightning Protection in Multiline Stations," "A Surge Impedance Analogue of a Large Generating Plant Switchyard," and "A Proposal to Use the Concept of the Coefficient of System Grounding in AIEE Standards."

Semiconductor Rectifying Devices and Inverters. Three papers, all by representatives of the General Electric Company and dealing with applications of silicon controlled rectifiers, were featured at a Wednesday morning session sponsored by the Semiconductor Rectifiers Committee. A paper by J. L. Fink and I. W. Macie discusses the silicon controlled rectifier (SCR) as a building block in power-conversion systems. Available ratings are being rapidly extended and characteristics greatly improved. It is predicted that the 1960's will witness an enormous expansion of solid-state converters and associated equipment.

An SCR inverter circuit which makes use of a new commutation method is described in a paper by W. McMurray and D. P. Shattuck. Here the small size, short turn-off time, and low forward voltage drop of the SCR are advantageously utilized to provide a flexible inverter with effective performance and small size.

A paper by P. D. Corey and A. L. Welford covers the design of a static inverter presently used as standard equipment in one of the newest commercial jet airliners. The inverter supplies a-c power for such items as engine ignition during flight emergencies, ground starts, and maintenance checkout.

S. P. Jackson, Power Equipment Company, Galion, Ohio, discussed some design considerations for a transistorized saturable current transformer amplifier.

Power Generation. Scientists have long been intrigued by the vast amount of power that is daily going to waste all about us in the wind, in the tides, from the sun, and to a lesser extent from the internal heat in the earth itself. P. E. Benner, J. B. McClure, and A. G. Mellor, in their joint paper, "The Development of Income Sources of Power," review specific proposals for generating power from the wind, tides, heat from the sun, temperature gradients in the oceans, and the steam from the earth's innards. The authors' purpose is to reveal the technical and economic problems involved and serve as a basis for evaluating these "income" sources of power for supplying present and future requirements.

J. J. Grebe, director of nuclear and basic research for the Dow Chemical Company, spoke on "Power from Nuclear Reactions." One of the reactions envisioned is the so-called "annihilation reaction" to power interplanetary ships. This reaction occurs when an electron and a positron attract and fall into one another. The author feels confident this annihilation energy will be harnessed by large electromagnetic fields, increasing the chance of electron-positron interaction adjacent to space vehicles so that this energy can be captured and converted into thrust.

R. J. Rosa of Avco-Everett Research Laboratory spoke on the possibilities for magnetohydrodynamic power generation, and J. Coltman, Westinghouse Research Laboratories, discussed thermionic power generation.

RECIPIENT of the William M. Habirshaw Award is Dr. S. B. Crary, systems analysis engineer, Electric Utility Engineering Section, General Electric Company. Charles Concordia *(left)* **of General Electric accepted the award for Dr. Crary from C. H. Linder, AIEE president.**

Radio Communication Systems. A fault-sensing and switching system that automatically guards the quality of a broadband (1,300 kc) transmission channel was described by D. H. Hesselgrave and M. H. Kebby, Lenkurt Electric Co., Inc., in their paper "The 57-A Microwave Path Protection System." Acting upon a loss in transmission level or an increase in noise, it transfers a communication traffic load from a regular channel to a normal unassigned standby channel. The transmission protection afforded by the standby channel is shared among as many as three regular channels.

The use of microwave video relay techniques by various Government agencies to remote radar data was described by Paul Hertel, Jr., Collins Radio Company. The remoting functions apply to the Federal Aviation Agency which began an expansion of their radar facilities in 1957 to cope with the problems of adequate air traffic control in the jet age of increasing traffic density.

F. H. Stelter and J. J. Sedik, Raytheon Company, discussed a microwave radio relay link for high definition radar. Specifically discussed was the system in use by the Harbor Defense Unit of the U. S. Navy which employs the methods of wideband data transmission using microwave telecommunications systems to transmit from a distance radar-derived intelligence and to permit supervisory control and the telemetering of radar equipment-status information. Equipment involved a high definition radar, a microwave relay link, and a remote indicator, developed by the Raytheon Company into an efficient harbor surveillance system.

Rotating Machinery. The advent of the modern digital computer has resulted in tremendous changes in the area of machine design. Many of the arithmetic barriers have been surmounted and, consequently, the designer is no longer forced to make many of the assumptions necessary to stay within simple mathematical expressions. H. K. Kesavan and H. E. Koenig, both of Michigan State University, discuss a digital computer program for commutation design to overcome the "arithmetic barrier" and reduce or eliminate design changes on the test floor.

L. Buchanan and N. Maupin, in their paper "Auxiliary Winding Design for Split-Phase Motors," develop a procedure for the design of an auxiliary winding after the main winding and auxiliary winding distribution are selected. The resulting motor should meet the locked rotor requirements such as torque, line amperes, circular mils per ampere in the auxiliary windings, and slot fullness; or the computation should definitely establish that not all these requirements can be met with the proposed main winding, auxiliary distribution, and rotor combination. The methods developed facilitate programming a digital computer so that the computer follows certain logical procedures to arrive at the best auxiliary winding.

Topics also discussed were "A Computer Design of Capacitor-Start Motor Start Windings" and "A New Criterion for Satisfactory Commutation."

Industrial Control. "High Accuracy Speed Control of a Paper Machine," by L. R. Hulls and R. Tickell, both of Remington Rand Univac, describes a transistorized speed regulator recently installed to control the master section of a paper machine. Requirements for such regulation are considered before various stages of control are discussed in detail. Starting and stopping of the machine, and synchronizing of the regulator at operating speed are explained.

The term "inductive load" is often seen in connection with ratings of contacts. At times, an attempt has been made to eliminate some of the ambiguity associated with this term by using a value of circuit "time constant" or L/R ratio to specify the type of load which the contacts might be required to interrupt. When the load consists of iron core inductances, further factors must be considered in specifying the characteristics of an inductive load. C. T. Evans and Roy Hyink, both of Cutler-Hammer Inc. (the former now retired), attempt to show why this is so in their paper, "Design of an Inductive Load for D-C Control Circuit Devices."

A paper by C. A. Lister, Square D Company, dealt with "Electro-Magnetic Brake with Controllable Torque."

Digital Computer Techniques. Machines alone can never solve the fundamental problems of information storage and retrieval. They only provide the means for implementing solutions which would not have been practical using manually operated systems. "Information Storage and Retrieval, Part II—Equipment Applications," by A. F. Glimm and R. D. Greenway, General Electric Company, discusses the factors involved in evaluating and specifying equipment and equipment configurations for information storage and retrieval systems. (An article by these authors, entitled "Information Storage and Retrieval—Dogs, Cats and Indexing," appeared in the September 1960 issue of *Electrical Engineering*, pp. 723-28.)

A method for teaching electrical engineering students the use of digital computers in solving electric machinery problems—especially with regard to iterative methods—is discussed in a paper by O. I. Franksen who is on leave of absence from the Technical University of Denmark and is now on a NATO fellowship at Rensselaer Polytechnic Institute, Troy, N. Y. By emphasizing the process of stating actual problems and formulating them in flow diagrams, more general principles are brought to light. The method is illustrated with an example of a power transformer winding design. The use of the international computer language, "Algol," is demonstrated and discussed.

E. B. Carne, Melpar Inc., deals with the ingredients of a properly magnetic memory drum. Proper design, he says, requires an appreciation of the effect on performance of such factors as rotor eccentricity, head-setting variations, head manufacturing tolerances, and storage surface variations. Problems associated with thermal mismatch of materials are discussed, and the necessity of operating large drums in a stable temperature environment is pointed out.

Wire and Data Communications. Telephone influence factor (TIF), which provides an index of the inductive influence of a power system waveshape on telephone circuits, is discussed in a paper by W. C. Ball, Bell Telephone Laboratories, and C. K. Poarch, Edison Electric Institute.

C. G. Griffith, Lenkurt Electric Company, described a repeater designed for a medium-haul cable carrier system, which features exceptionally low-power requirements through the use of transistors.

F. I. Andrews, Jr., Bell Telephone Laboratories, reported on test instrumentation recently developed for simulating the principal types of transmission impairments to be encountered on voice-frequency telephone circuits. By use of this equipment, together with conventional random-data signal generators and error comparators, it is possible to evaluate data systems over a wide range of transmission characteristics.

Some of the techniques employed to measure envelope delay at audio frequencies were described by I. M. Stump of the Stromberg-Carlson Division of General Dynamics Corporation.

Switchgear and Substations. Four papers were presented at a Thursday morning session sponsored jointly by the Switchgear and Substation Committees. In response to a growing demand from the industry, a compact, low-cost, easy-to-mount high-speed grounding switch, in a range of 15 through 230 kv has been developed by the I-T-E Circuit Breaker Company, as reported by K. A. Thallner.

When surge protective equipment is selected and applied, it should be properly co-ordinated with the impulse withstand characteristics of all apparatus which it is to protect. A method proposed in a paper by Otto Naef, American Electric Power Service Corporation, and C. E. Asbury, Commonwealth Associates, Inc., permits co-ordination of the different insulations of a circuit breaker with respect to each other and with respect to the volt–time characteristics of a protective device.

Other papers presented included a report by a Switchgear Committee working group covering a proposed AIEE Standard for low-voltage cartridge fuses (600 volts or less), and a review of the development of line entrance gaps for substation insulation protection by T. F. Watson and R. Hiatt, both of Commonwealth Associates, Inc.

Basic Sciences. R. L. Peek, Jr., Bell Telephone Laboratories, discussed the characteristics of magnetic reeds, as used in sealed-reed relays. His paper includes a design and performance analysis, as well as expressions for the estimation of speed of operation.

A method of minimization of Boolean functions which is somewhat more direct and simpler than previous methods was described by F. B. Hall, Argonne National Laboratory.

Application of statistical quality control techniques to watt-hour meter testing is the subject of a paper presented by C. L. Matz, Commonwealth Edison Company. It is maintained that scientifically designed sampling plans will evaluate the accuracy of meter performance more effectively and at lower cost than the present method.

Transmission and Distribution. "Transmission Line Construction in Lakes" by A. V. Price is a summary of the salient features of transmission lines constructed partly or entirely in lakes. A characteristic of lines in lakes is the relatively high cost of tower foundations, often exceeding 50% of the total cost of the line. This compares with foundation cost for normal lines amounting to 15 to 25% of the total cost.

"Concrete Guy Anchor Tests" by C. S. Bucholz describes the design and testing of precast concrete anchor slugs suitable for guying aerial pole-line construction at the Hanford Works in the state of Washington.

Other papers were the "Effect of Bundle-Conductor Field Influence on EHV Transmission Line Design" and "Decoupling of Transmission Lines to Radio Influence Voltages"

AIEE Future Meetings

AIEE-NEMA Application of Electrical Insulation Conference*
Conrad Hilton Hotel
Chicago, Ill.
December 5-8, 1960

AIEE-IRE-ACM Eastern Joint Computer Conference*
Hotel New Yorker
New York, N. Y.
December 11-14, 1960

AIEE-IRE-ASQC-EIA Reliability & Quality Control Conference*
Bellevue-Stratford Hotel
January 9-11, 1961

Winter General Meeting*
Hotel Statler
New York, N. Y.
January 29-February 3, 1961

AIEE-IRE-U of P International Solid-State Circuits Conference
University of Pennsylvania
Philadelphia, Pa.
February 15-17, 1961
(Final date for †TP—closed, ‡CP Syn.—Dec. 2, CPMs—Dec. 12)

AIEE-IAS-IRE-U of P Engineering Aspects of Magnetohydrodynamics Symposium
University of Pennsylvania
Philadelphia, Pa.
March 9-10, 1961

South East District Meeting
Jung Hotel
New Orleans, La.
April 5-7, 1961
(Final date for †TP—Jan. 5, CPMs —Jan. 30)

Rubber and Plastics Industries Conference
Sheraton Hotel
Akron, Ohio
April 10-11, 1961
(Final date for †TP—Jan. 10, ‡CP Syn.—Jan. 24, CPMs—Feb. 3)

Materials Handling Conference[1]
Pick-Congress Hotel
Chicago, Ill.
April 11-12, 1961
(Final date for †TP—Jan. 11, ‡CP Syn.—Jan. 26, CPMs—Feb. 6)

Electric Heating Conference[1]
Sheraton-Lincoln Hotel
Indianapolis, Ind.
April 11-12, 1961
(Final date for †TP—Jan. 11, ‡CP Syn.—Jan. 26, CPMs—Feb. 6)

Cement Industry Conference
Sheraton-Cadillac Hotel
Detroit, Mich.
April 18-20, 1961
(Final date for †TP—Jan. 18, ‡CP Syn.—Feb. 2, CPMs—Feb. 13)

Great Lakes District Meeting
Hotel Pick-Nicolett
Minneapolis, Minn.
April 19-21, 1961
(Final date for †TP—Jan. 19, CPMs —Feb. 13)

AIEE-ASME Railroad Conference
Sir Francis Drake Hotel
San Francisco, Calif.
April 20-21, 1961
(Final date for †TP—Jan. 20, ‡CP Syn.—Feb. 3, CPMs—Feb. 14)

Joint Rural Electrification and Appliance Conference
Kentucky Hotel
Louisville, Ky.
May 1-3, 1961
(Final date for †TP—Jan. 31, ‡CP Syn.—Feb. 15, CPMs—Feb. 24)

AIEE-IRE-EIA-WCEMA Electronic Components Conference
Jack Tar Hotel
San Francisco, Calif.
May 2-4, 1961
(Final date for †TP—Feb. 2, ‡CP Syn.—Feb. 16, CPMs—Feb. 26)

Spring Textile Conference
Heart of Atlanta Motel
Atlanta, Ga.
May 4-5, 1961
(Final date for †TP—Feb. 3, ‡CP Syn.—Feb. 17, CPMs—Feb. 28)

AIEE-IRE-ACM Western Joint Computer Conference
Ambassador Hotel
Los Angeles, Calif.
May 9-11, 1961
(Final date for †TP—Feb. 8, ‡CP Syn.—Feb. 23, CPMs—Mar. 6)

Packaging Industry Conference
New Ocean House
Swampscott, Mass.
May 15-16, 1961
(Final date for †TP—Feb. 14, ‡CP Syn.—Feb. 28, CPMs—Mar. 10)

North Eastern District Meeting
Statler Hotel
Hartford, Conn.
May 17-19, 1961
(Final date for †TP—Feb. 16, CPMs —Mar. 13)

AIEE-IRE Globe-Communication V Conference[2]
Chicago, Ill.
May 22-24, 1961
(Final date for †TP—Feb. 21, ‡CP Syn.—Mar. 8, CPMs—Mar. 17)

AIEE-IRE-ISA-IAS-ARS National Telemetering Conference[2]
Sheraton Towers
Chicago, Ill.
May 22-24, 1961
(Final date for †TP—Feb. 21, ‡CP Syn.—Mar. 8, CPMs—Mar. 17)

Fractional Horsepower Motors Conference
Biltmore Hotel
Dayton, Ohio
May 23, 1961
(Final date for †TP—Feb. 22, ‡CP Syn.—Mar. 9, CPMs—Mar. 20)

Summer General Meeting
Cornell University
Ithaca, N. Y.
June 18-23, 1961
(Final date for †TP—Mar. 20, ‡CP Syn.—Mar. 30, CPMs—Apr. 14)

Pulp and Paper Conference
Kalamazoo, Mich.
June 21-23, 1961
(Final date for †TP—Mar. 23, ‡CP Syn.—Apr. 7, CPMs—Apr. 17)

Aero-Space Transportation Conference
Benjamin Franklin Hotel
Philadelphia, Pa.
June 26-30, 1961
(Final date for †TP—Mar. 28, ‡CP Syn.—Apr. 12, CPMs—Apr. 21)

AIEE-AIChE-ASME-IRE-ISA Joint Automatic Control Conference
University of Colorado
Boulder, Colo.
June 28-30, 1961
(Final date for †TP—Mar. 30, ‡CP Syn.—Apr. 14, CPMs—Apr. 24)

Pacific General Meeting
Hotel Utah
Salt Lake City, Utah
August 23-25, 1961
(Final date for †TP—May 25, ‡CP Syn.—June 5, CPMs—June 19)

AIEE-ASME Engineering Management Conference
Hotel Roosevelt
New York, N. Y.
September 14-15, 1961
(Final date for †TP—June 16, ‡CP Syn.—June 30, CPMs—July 11)

Petroleum Industry Conference
Jung Hotel
New Orleans, La.
September 17-20, 1961
(Final date for †TP—June 19, ‡CP Syn.—July 5, CPMs—July 14)

Fall General Meeting
Statler-Hilton Hotel
Detroit, Mich.
October 15-20, 1961
(Final date for †TP—June 14, ‡CP Syn.—July 27, CPMs—Aug. 11)

*Final date for submitting papers—closed
[1]No conflict in subject matter
[2]Planned to coincide

†TP—Transactions Paper
‡CP Syn.—Conference Synopsis
CPMs—Conference Manuscript
DPMs—District Manuscript
(District Paper Synopses should be directed to the District Meeting Committee)

**Transactions and conference papers must conform to the requirements in *Author's Guide*.
For a copy, write to E. C. Day, 33 W. 39th St., New York 18, N. Y.**

Conference Papers Open for Discussion

Conference papers listed below have been accepted by AIEE *Transactions* and are now open for written discussion until December 27. Duplicate double-spaced typewritten copies of each discussion should be sent to E. C. Day, Assistant Secretary for Technical Papers, AIEE, 33 W. 39th St., New York 18, N. Y., on or before December 27.

59-1123	**An Algorithm for Determining Minimal Normal Forms of an Incomplete Truth Function.** *T. H. Mott, Jr.*
60-211	**Effective Value of Direct Voltage Ripple.** *E. J. Diebold*
60-864	**Application of Silicon-Controlled Rectifiers in a Transistorized High-Response D-C Servosystem.** *Clarence Cantor*
60-992	**Automatic Precipitation and Temperature Reporting Over a Very-High-Frequency Radio System.** *E. J. Warchol, M. S. Sachs, H. S. Lorentson*
60-1223	**Minimization of Multiple-Output Switching Circuits.** *R. B. Polansky*
60-1290	**A Method of Calculating Gain and Phase Margins from Pole-Zero Diagrams.** *F. H. Schlereth*

Preprints may be purchased at 50¢ each to members, $1.00 to nonmembers, if accompanied by remittance or coupons. Please order by number and send remittance to: AIEE Order Department, 33 W. 39th St., New York 18, N. Y.

Board and Executive Committee Meet on AIEE Policy and Administration

TO take advantage of the breadth of representation provided by the expansion of the Board of Directors and the Executive Committee, a series of meetings were held beginning on September 20 and carried through the Fall General Meeting October 10-14 in Chicago, Ill. The Executive Committee undertook to clear the Board agenda of administrative detail by meeting in September, prior to the Board Meeting in Chicago, and again at the end of the week of the Fall General Meeting. The Board thus freed, and cognizant of the actions and agenda of the Executive Committee, devoted two 3-hour sessions to a review of the over-all position and problems of the Institute and discussion of its long-range objectives and policies.

President Linder Presents Broad Picture

Setting the stage for what will doubtless be a year-long study by the Board, President Linder reviewed the present state of technology, the rate of its expansion, and the needs and opportunities presented to the societies for exercising leadership through effective management in an attack on the boundary problems of science and its application to individual and national requirements. The objectives of the Institute would appear adequate if fully implemented:

1. To provide a forum for the exchange of information and ideas emphasizing the frontiers of knowledge and practice and bringing together the wide range of disciplines essential to the adequate handling of most current and urgent problems.

2. A concern for the education of the oncoming generation of engineers as expressed through insistence on high standards of performance in curricula of depth and quality, and active support of lifelong engineering education.

3. A concern with professional ethics, stature, and recognition.

The president then proceeded to assess the capabilities of the Institute itself, and through its associations with other bodies, to achieve these objectives in the present technological environment. Illustrating the nature of the environment and the response of the Institute and other engineering societies to it by means of a series of charts and graphs, he encompassed the whole range of AIEE activities. The rapid growth in the number of societies, meetings, and publications was documented. Evidence of overlappings, duplications, and possibilities for improved efficiency through co-ordination were noted as opportunities for effective intersociety cooperation.

EUSEC Conference in Brussels

As an illustration of the breadth of intersociety co-operation, Mr. Linder reported on the 1960 meetings of the Conference of Engineering Societies of Western Europe and the United States, (EUSEC), in Brussels August 29-September 3, which he attended as AIEE representative. Both at the conference and in preliminary meetings with the officers of the three British Institutions in London, the president found many problems in common among the European and American societies. Notable progress appears to have been made in EUSEC, not only through the assembly but also through continuous exchanges among the societies, especially in the definition and appraisal of educational programs.

Internal Problems

Within the AIEE itself, the structure, policies, and programs of committees, publications, meetings, finances, and the extent of member active participation were analyzed and illustrated.

The Board adjourned at noon to attend a luncheon for the five medalists to be honored at the afternoon general session of the Fall General Meeting and reconvened in the evening for a discussion of some specific questions introduced in the president's morning presentation.

These questions included meeting co-ordination within the AIEE and among societies, the progress of the Functional Plan, the development of Institute Technical Groups, the size and tenure of membership on Technical Committees, co-operation with science as well as engineering organizations, quality of papers and their classification and dissemination. A summary of the president's morning presentation and the evening discussion, including illustrations, has been made and distributed to the Board of Directors for study and use in its continuing program of policy development.

Administrative Business

A summary of the actions taken by the Executive Committee and the Board of Directors on September 20 and October 10 and 14 follows:

AIEE Joins AFIPS

The National Joint Computer Committee, consisting of the Association for Computing Machinery, the Institute of Radio Engineers (IRE), and AIEE, which has functioned for 10 years conducting conferences in the East and West annually, is in the process of reorganizing into an autonomous federation with a permanent staff and expanded membership. The new name is American Federation of Information Processing Societies (AFIPS). The Executive Committee of AIEE approved in principle AIEE affiliation with AFIPS and delegated to the Technical Operations Department authority to carry through the arrangements within designated limits.

Fellow References Confirmed, Bylaw Omission

An omission in the bylaws (20.030) as printed in the October issue of *Electrical Engineering* was noted. The Board confirmed that a proposal for Fellow must still be accompanied by reference to five (5) Fellows.

Nominating Committee Representatives Elected

The Board elected six representatives and five alternates to the Institute Nominating Committee which meets January 30, 1961, to select nominees for Institute officers for 1961-62, as follows: Repre-

sentatives—Hendley Blackmon, R. B. Gear, C. T. Hatcher, N. F. Rode, J. C. Strasbourger, R. T. Weil, Jr. Alternates—F. S. Bacon, J. H. Foote, E. I. Green, C. T. Pearce, and P. G. Wallace.

Institute Technical Groups To Be Announced

The Technical Operations Department was authorized to announce the Institute Technical Group Plan in a mailed message to all members providing opportunity for each to signify his interest and indicate the group with which he wishes to be associated. By this means, it is intended to make available to each member an intimate association with the work of the Institute now carried on by the Technical Committees.

Exhibit Set for 1962 WGM

AIEE has entered into a contract with Reber-Friel Expositions Company to manage, under the sponsorship of the Institute, an Electrical Engineering Exposition in the New York Coliseum as part of the 1962 Winter General Meeting program. Exhibits will be chosen to bring the newest developments in all fields of electrical engineering to the members attending the meeting. Arrangements will be made to hold at least 27 sessions in specially fitted rooms in the exhibit area.

EJC Board Appointments

Hendley Blackmon was appointed to replace C. H. Linder as AIEE representative on the Engineers' Joint Council (EJC) Executive Committee. Prof. R. T. Weil, Jr., was appointed to replace D. L. Greene as a member of the EJC Board of Directors.

Joint Medal Boards Revised

The American Institute of Chemical Engineers was added as the fifth member organization to be represented on the John Fritz Medal Board of Award. Terms of the representatives were reduced from 4 to 3 years.

The Institute of the Aerospace Sciences has been included in the Board of the Elmer A. Sperry Award.

ECPD, EJC, and NSPE Officers To Confer

Approval was given to a proposal of the Past President's Task Force on Unity calling for the presidents and vice-presidents of the Engineers Council for Professional Development (ECPD), EJC, and the National Society of Professional Engineers (NSPE) to meet quarterly for the purpose of finding and recommending procedures for:

(a) Eliminating undesirable duplication of effort;

(b) Improving effectiveness and efficiency in the total society effort;

and for the purpose of:

(a) Supporting one another's programs . . . ;

(b) Undertaking other steps in the best interests of the profession.

This proposal has been approved by the Board of Directors of EJC, the Council of ECPD, and accepted by NSPE.

AIEE-IRE Co-operation

Members of AIEE or IRE will, after January 1, 1961, be accepted as members in the second Institute in the equivalent grade without payment of entrance fee and without filing an experience record, according to action taken by the Boards of the two Institutes.

The Boards of the two Institutes also agreed to organize joint Standards Committees in areas of mutual interest to avoid duplication and conflicting publications.

Empire District Fulfills UEC Quota

MAILING a check in the amount of $260 from the Niagara Frontier Section Treasury for the United Engineering Center (UEC) Building Fund are: (*left to right*) Prof. F. P. Fischer, Section secretary-treasurer, and E. V. Ellett, Section chairman. This was the final act in making Empire District No. 1 the first Section in the Institute to reach 100% of its quota. Prof. Fischer is also student counselor at the University of Buffalo and the district representative of the Student Activities Committee.

ATTENDING the District No. 1 Executive Committee Meeting held October 21 in Buffalo, N. Y., were: (*Front row, left to right*) E. V. Ellett, chairman, Niagara Frontier Section; C. G. Moon, District representative, Membership Committee; L. C. Holmes, Past District vice-president; J. D. Stickler, District secretary; C. E. Gaylord, District vice-president; F. P. Fischer, District representative, Student Activities; R. A. Nevin, District representative, Technical Operations Department; J. M. Geiger, chairman, District Prize Paper Committee, and R. N. Born, secretary, Rochester Section. (*Back row, left to right*) E. G. Samolis, chairman, Syracuse Section; C. C. Roberts, chairman, Erie Section; R. W. McCarty, chairman, Rochester Section; R. D. Batley, chairman, Binghamton Subsection; E. G. Ball, vice-chairman, Niagara Frontier Section; M. L. Rowley, alternate District representative, Sections Committee; S. P. Bartles, chairman, District Development Committee; N. S. Hibshman, executive secretary, Headquarters; A. J. Rokicki and E. J. Rahill, guest, member of Niagara Frontier Section; F. C. Casavant, secretary, Syracuse Section, and H. J. Fiedler, vice-chairman, Schenectady Section.

R. C. Sogge

J. H. Foote

AIEE Standards Specialists Are Recipients of ASA Medals

TWO gold medals, the highest awards in the field of national standards work, were presented recently to J. H. Foote (AM '18, F '32, Member for Life, AIEE president 1959-60), vice-president of Commonwealth Services Inc., and R. C. Sogge (M '35, F '53), retired manager of the Standards Division of General Electric Company. The presentation was made in conjunction with the 11th National Conference of Standards, sponsored by the American Standards Association (ASA).

Mr. Foote received the Howard Coonley Medal, awarded each year by the ASA to an executive who has served by advancing the national economy through voluntary standards. The citation, which referred to Mr. Foote as "one of the foremost advocates in the promotion and advancement of standardization," stated also that "through his standards activities, both here and abroad, he has served the voluntary standards movement with remarkable foresight, ingenuity, leadership and accomplishment."

The Standards Medal, awarded to Mr. Sogge, is given annually to an individual who has served the voluntary standards movement through leadership in the actual development of standards. Mr. Sogge's citation read that "his leadership in the international field has led to outstanding participation of the electrical and electronic industries of his own and other countries" in the work of the International Electrotechnical Commission.

Procedures from Author to Audience Discussed at Forum of Technical Chairmen

PROCEDURES to improve meetings, reduce the time from authors' work to audience reception, and the exploding technology of the current era were discussed at the 24th Forum of Technical Committee Chairmen. The meeting was opened by F. L. Lawton, chairman of the Technical Operations Department.

Adjusting to the Explosive Technology Era

Attention was drawn by President Linder to the rapid expansion of technology during present times, where research and engineering development run in parallel rather than in tandem, and the sharp reduction in elapsed time from the reporting of scientific results to actual engineering applications. Engineering societies should be flexible and adapt themselves to these rapidly changing conditions lest they die on the vine. Societies cannot be everything to everybody, and a selection of prime objectives will have to be made since the western world cannot afford to "Re-invent the wheel every day of the week."

In respect to the quality of papers, President Linder explained that what is meant by quality must first be defined. Some papers are almost scientific, others are aimed at proving technical capability, still others prove economic feasibility, and others treat interests of engineers who operate and maintain equipment. Each class cannot be compared to the other. Nevertheless, within each group of interests, there are individual papers which are good and bad and there is where to apply the quality controls. The interests of the members should not be mixed with the output of authors in judging the quality, and more care should be exercised in terminology when considering "quality." With respect to joint special technical conferences with other societies, the president pointed out that in this complex era, only the surface has been scratched. Instead of two or three joint sponsorships, perhaps five or six would be more appropriate. For example, in the area of magnetic steel development today, the chemist, mechanical engineer, electrical engineer, metallurgist, and physicist, must be called in.

Special technical conferences which cut across the disciplines would bring together more people having similar and complementary interests, thus cutting down on the duplication of conferences and symposia. Duplication of effort is becoming an abuse with high industrial cost which presents a challenge and opportunity to the societies to do something about the situation.

In conclusion, President Linder pointed out that there are some 1,600 technical societies, 10% of which are in the engineering area with "splintering by the day." Some of the older societies have not proved sufficiently flexible to move forward with the changing times.

From Author to Audience

The chairman of the Technical Operations Department, F. L. Lawton, outlined in a talk entitled "Pencil to Paper or Author to Audience" the pitfalls lurking for authors and technical committee chairmen who fail to read and abide by the "Author's Guide" and to process promptly the review forms of papers. Authors should submit papers prepared in the style prescribed in the "Author's Guide."

Copies of this guide should be distributed to all authors by those inviting papers to be prepared, and the authors should submit their papers to the Assistant Secretary of Technical Papers before the deadlines published in *Electrical Engineering* with an indication of the sponsoring committee who invited the paper or an indication of the committee the author believes interested in the subject matter. Reviewers should return the papers promptly within the time limits allowed indicating the meeting and session for which the paper is approved. Mandatory changes cannot be accomplished within the 90-day closing date rule, and where mandatory changes are required, postponement of the presentation is necessary. Failure to comply strictly with the "Author's Guide" or the reviewing procedure delays the time span from author to audience and results in extra work on the part of the headquarters staff. A panel of staff members answered questions which were raised in regard to the procedure.

In discussion which ensued, J. Meszar proposed that a monitoring subcommittee should be established which would sample the content of papers, visit the sessions selected by a sampling process, and attempt to report on audience reaction.

Toward a possible improvement in sessions management, the "reporter system"

Membership in the American Institute of Electrical Engineers, including a subscription to this publication, is open to most electrical engineers. Complete information as to the membership grade, qualifications, and fees may be obtained from Mr. N. S. Hibshman, Secretary, 33 West 39th Street, New York 18, N.Y.

on a trial and evaluation basis was proposed. In this system, an expert chosen by the technical committee studies the papers in advance, and presents them, pointing out the relationship to each other and to the present state of the art. A written summarization of the high points of each paper is prepared in advance, and distributed to the authors and other participants. Questions are also prepared to get the discussion underway, and the authors sit as a panel for discussions only. If two committee-sponsored sessions, each consisting of three or four *Transactions* and printed conference papers, were held, one a standard session, the other the "reporter system," the Ad Hoc Committee could by feedback from the respective audiences make a comparison and develop the merit of the "reporter system," if any.

Special Technical Conference Policies and Procedures

In the absence of Dr. S. R. Warren, Jr., Secretary I. S. Coggeshall reported that a "Policy for AIEE Special Technical Conferences" had been adopted and that this document together with "AIEE Special Technical Conference Manual" would become a part of the Technical Operations Department Manual for the guidance of all AIEE independent and jointly sponsored special technical conferences.

Institute Technical Groups

Technical Vice-President P. K. McElroy, chairman of an Ad Hoc Committee on Institute Technical Groups, reported informally that policies had been established and three documents for general use were being drawn up as follows: (1) Procedures of the National Organization to Co-ordinate Institute Technical Groups; (2) ITGs—an Innovation of Benefit to AIEE Members; and (3) Information for Administrators of ITGs. Plans are to produce item (2) ITGs—an Innovation of Benefit to AIEE Members in the January 1961 issue of *Electrical Engineering*, and there will be a separate mailing for all Members in a distinctive envelope containing a reply card for receiving suggestions for the ITGs appropriate to the six divisions and for expressions of personal interest in joining the proposed ITGs. The matter will also be brought to the attention of the Sections through the District Technical Operations Department representatives.

Midwest Student Branch Chairmen Attend National Electronics Conference

DELEGATES from 48 schools within a 400-mile radius of Chicago, Ill., were guests of the National Electronics Conference (NEC) in Chicago, October 9-11, and took part in the student activities program there.

The delegates, who were mainly the chairmen of Student Branches at their schools, had an opportunity to view the extensive NEC exhibits and hear technical papers on late developments in many areas of electronics. On October 11, they participated in activities aimed at strengthening their Branch operations. These consisted of a panel discussion on Branch activities, and a trial run of the "After Graduation" panel program which AIEE is encouraging around the country this Fall.

Student Activities Reviewed

After words of world perspective and challenge from R. L. McFarlan, president of the Institute of Radio Engineers, and C. H. Linder, AIEE president, the panel on Student Branch activities got under way. The panelists discussed what they are trying to do at their Branches and the successes and failures that have resulted. Discussion from the floor was spirited and many ideas about Branches were exchanged. (See "Closing the Loop," *EE Digest*, November 1, 1960.) The panelists were Lyle Feisel, Iowa State University; Vernon Gross, Rose Polytechnic Institute; John Scobee, University of Missouri; and L. E. Thompson, Case Institute of Technology. The moderator was Dr. W. L. Everitt, dean of engineering at the University of Illinois.

"After Graduation—What" Panel

Student activities on Tuesday afternoon included a pilot-run of the "After Graduation" panel program. The purpose of this program is to provide students with factual information about careers in electrical engineering.

The panel has four or five practicing electrical engineers, picked to answer questions about jobs submitted by student members prior to the meeting. In the pilot-run, the questions were submitted by the student chairmen, and were answered by four engineers chosen by W. T. Larner, chairman of the Chicago AIEE Section.

Participation in and response to this program by Branch chairmen and panelists alike was enthusiastic. The moderator for the panel was D. E. Garr, chairman of the AIEE Student Branches Committee, which is promoting the "After Graduation" panel around the country as a Branch-Section activity. Posters and Question Blanks for the program were supplied by AIEE Headquarters.

In charge of student arrangements at NEC were Dr. M. E. Van Valkenburg, University of Illinois, and Stanley Krupnik, Jr., AIEE counselor at Marquette University.

QUESTIONS from student delegates to the NEC were answered by (*left to right*) L. C. Latourette, consulting engineer for Pioneer Service and Engineering Co.; D. R. Whitlow, sales engineer for Aluminum Company of America; T. H. McGreer, research engineer for Argonne National Laboratories; and J. H. Enenbach, District marketing manager for Illinois Bell Telephone Company. Moderator for the panel was (*right*) D. E. Garr, chairman, AIEE Student Branches Committee, and manager, light military electronics department, General Electric Company. A typical question at this panel meeting was: "What does an electrical engineer do, and how does he get ahead?"

PAST PRESIDENT J. H. Foote *(upper photo, right)* **was presented with a retiring president's scroll by J. J. Fredrickson, Michigan Section chairman, at a recent Section meeting. H. R. Wall of Consumers Power Company received a Fellow certificate at the same meeting** *(photo below)*. **Shown are:** *(left to right)* **Mr. Wall; A. W. Rauth, AIEE District vice-president; Dr. J. L. Page, area co-ordinator for Midwest Program of Air-Borne Television Instruction, who spoke at the meeting; and Mr. Fredrickson.**

R. J. Vanderburg

Michigan Section Hears About Air-Borne TV Courses

Educational courses telecast from an airplane flying at high altitude over North Central Indiana will begin demonstrations in February 1961. This was disclosed at a recent meeting of the Michigan Section, AIEE, by Dr. J. L. Page of Michigan State University, area co-ordinator for the Midwest Program of Air-Borne Television Instruction.

Participating schools in six states—Indiana, Illinois, Kentucky, Michigan, Ohio, and Wisconsin—will receive these telecasts. A full academic year of telecasting will begin in September 1961.

During the meeting, J. H. Foote, who served as AIEE president in 1959-60, was presented with a retiring president's scroll in recognition of his efforts as AIEE president.

Another feature of the meeting was the presentation of a Fellow certificate to H. R. Wall of Consumers Power Company by A. W. Rauth, AIEE District vice-president.

JACC Will Take Place June 28-30 in Boulder, Colo.

The 2nd Joint Automatic Control Conference (JACC) will be held on the University of Colorado campus, Boulder, Colo., on June 28-30, 1961. The conference is sponsored jointly by the AIEE, the Instrument Society of America (ISA), the American Institute of Chemical Engineers (AIChE), the American Society of Mechanical Engineers (ASME), and the Institute of Radio Engineers (IRE), and is the nation's only annual conference devoted entirely to technical discussion of automatic control. Session categories are expected to include process dynamics, techniques of control system theory, adaptive control, new components, systems testing, and others.

A call for papers has been issued by Prof. H. M. Paynter, mechanical engineering department, Massachusetts Institute of Technology (MIT), the 1961 general program chairman. All authors are asked to send brief abstracts promptly, with a rough draft of the entire paper before the end of the year. Abstracts and rough drafts are to be sent to the program chairman of the authors' representative society for consideration.

These program chairmen are: ISA—J. L. Harned, Research Laboratory, General Motors Corporation, Warren Mich.; AIChE—Nathan Gilbert, chemical engineering department, University of Cincinnati, Cincinnati 21, Ohio; AIEE—Kan Chen, New Products Laboratory, Westinghouse Electric Corporation, P. O. Box 10596, Pittsburgh 35, Pa.; ASME—R. E. Kalman, Research Institute for Advanced Study, 7212 Bellona Ave., Baltimore 12, Md.; IRE—Robert Kramer, Electronic Systems Laboratory, MIT, Cambridge 39, Mass.

IAS Invited To Participate in Presentation of Sperry Award

The Elmer A. Sperry Board of Award has invited the Institute of the Aerospace Sciences to become the fifth society participating in administration of the award. The four others are the AIEE, the American Society of Mechanical Engineers, the Society of Automotive Engineers, and the Society of Naval Architects and Marine Engineers.

The Elmer A. Sperry Award, consisting of a bronze medal, a certificate, and a biography of Dr. Sperry, is made annually to an individual or group in recognition of "a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea, or air." It was established in 1955 by Dr. Sperry's daughter Helen, who is Mrs. R. B. Lea in private life, and son, E. A. Sperry, Jr., to commemorate the life and achievements of Dr. Sperry and his variety of contributions to so many types of transportation.

Winners of the award have been: 1955, W. F. Gibbs; 1956, D. W. Douglas; 1957, H. L. Hamilton, R. M. Dilworth, E. W. Kettering, and the Electrical Engineering,

Mechanical Engineering, Locomotive, and Controls Sections of the engineering department of the Electro-Motive Division of General Motors; 1958, the late Dr. Ferdinand Porsche, Dr. Heinz Nordhoff, and their co-workers in Volkswagenwerk; 1959, the de Havilland Aircraft Company Ltd., citing Sir Geoffrey de Havilland, C. C. Walker, the late Major Frank B. Halford, and their co-workers; and in 1960, F. D. Braddon.

Technical Papers Sought for Telemetering Conference

A request for abstract submission has been issued for the National Telemetering Conference (NTC) to be held May 22-24, 1961, at the Sheraton Towers Hotel in Chicago, Ill.

The deadline for abstracts will be December 20. All papers will be selected by January 15, and the papers should be in for publication on March 1. The program will be mailed out April 1 and the *Proceedings* completed on May 1.

"Science and Education in Telemetry" is the theme for the NTC, an annual symposium designed to aid in the technical interchange of ideas concerning the theory and practice of telemetry. The conference brings together representatives of industry, education, and the Government to hear discussions of new developments and techniques and past experiences, and to view the latest commercially available equipments.

The conference is sponsored jointly by five technical societies—AIEE, the American Rocket Society, the Institute of Aero-Space Sciences (IAS), the Institute of Radio Engineers (IRE), and the Instrument Society of America.

Chairmanship of the NTC is rotated among the societies. The chairman for this year will represent the IAS, and the vice-chairman, the IRE.

The technical program for the 1961 conference is tentatively scheduled as follows:

Monday, May 22

9:30 a.m. Session

Workshop: Telemetry standards

1:30 p.m. Sessions

Transducers
Space Data Acquisition Systems
Data Processing and Presentation

Tuesday, May 23

9:00 a.m. Sessions

Signal Conditioning
Bio-Medical Telemetering
PCM Systems

1:30 p.m. Session

Workshop: Telemetry Education in the 60's

Wednesday, May 24

9:00 a.m. Sessions

Environmental Measurements
Underwater Measurements
R-F Components and Techniques

1:30 p.m. Sessions

Flight Test Data Systems
Transistorization Progress
Industrial Data Transmission

John Tyner

TELEMETERING experts are making early arrangements for the National Telemetering Conference to be held May 22-24, 1961, at the Sheraton Towers Hotel in Chicago, Ill. Conference leaders are: (*left to right*) Raymond Berg, treasurer; R. G. Brown, chairman; and Jack Becker, program chairman, all of the A-C Spark Plug Division, General Motors Corporation, Milwaukee, Wis., and F. C. Finch, exhibit manager, Long Beach, Calif.

Five papers are being sought for each technical session. Selected authors will be requested to present a 15- to 20-minute summary of and epilogue to their papers at the conference. They will then form a 5-man panel for question answering and subject discussion. The chairman will be moderator and discussion stimulator.

The workshop will be made up of five or six recognized authorities on the subject and representing varying views or backgrounds. Each man will make an opening statement summarizing his position on the subject and then the chairman will moderate and guide conversation. Questions from the floor may be accepted by the chairman at any time.

Abstracts and correspondence regarding the conference program should be directed to the program chairman: Jack Becker, A-C Spark Plug Division, General Motors Corporation, Milwaukee 1, Wis.

National Electric Code Studied

SOUTH TEXAS SECTION, AIEE, and the City Public Service Board of San Antonio, Texas, co-sponsored a meeting on October 13 at the Villita Assembly Hall. Shown are: (*left to right*) J. T. Deely, manager, administrative services, City Public Service Board; O. K. Coleman, vice-president, Duncan Electric Company, Lafayette, Ind.; W. F. Payette, Jr., South Texas Section, chairman; and H. A. Tynan, manager, electric system, City Public Service Board. Invitations were sent to all interested persons in the electrical industry in the San Antonio—Austin Area. The featured talk of the evening was by Mr. Coleman on "Principal Changes in the 1960 National Electric Code—Service and Grounding." There were approximately 400 in attendance.

MEMBERS of the jury which selected Eta Kappa Nu's Outstanding Young Electrical Engineer of 1960 are as follows: (*left to right*) J. C. McPherson, IBM; B. R. Teare, Carnegie Institute of Technology; A. Naeter, Eta Kappa Nu; W. R. Clark, AIEE; E. I. Green, Bell Telephone Laboratories; R. G. Slauer, Illuminating Engineering Society, and J. H. Craig, Eta Kappa Nu.

Eta Kappa Nu Selects K. H. Olsen as Outstanding Young Engineer of 1960

K. H. OLSEN of Bedford, Mass., has been named Outstanding Young Electrical Engineer of 1960 by Eta Kappa Nu Association, national electrical engineering honor society. Honorable mentions in this year's national competition are W. B. Green of Greensburg, Pa.; R. R. Johnson of Phoenix, Ariz.; and T. H. Thompson of Basking Ridge, N. J.

Formal Presentation Scheduled

The 1960 award is the 24th since 1936. Formal presentation of the awards will be made at a banquet on January 30, 1961, during the Winter General Meeting of the AIEE.

Mr. Olsen, a native of Bridgeport, Conn., is 34 years old. He received the B.S. and M.S. degrees in electrical engineering in 1950 and 1952, respectively, from the Massachusetts Institute of Technology (MIT). As a graduate student, he invented a magnetic matrix switch for use with coincident current magnetic memories. Following graduation, as a staff member of the Digital Computer Laboratory of MIT, he supervised the group responsible for the first digital computer to use magnetic core random-access memory. He was one of the leaders in the design of computers for the Sage air defense system. Later, he was one of the first to build a high performance digital computer using transistors. In 1957, Mr. Olsen founded and became president of Digital Equipment Corporation, a concern that has created and marketed successfully transistorized building blocks for the computer industry.

In his personal life, Mr. Olsen has taken exceptional leadership in the Park Street Congregational Church of Boston as deacon and superintendent of Sunday School and chairman of committees. He is a lecturer in applications of new electronic devices.

Dr. W. B. Green of Greensburg, Pa., who received honorable mention, is 32 years old and a graduate of Johns Hopkins University in 1950. He received the M.S. degree in 1952 and the Ph.D. degree in 1955, both from MIT. Dr. Green has been with the Westinghouse Electric Corporation, semiconductor department, Youngwood, Pa., since 1955. He is one of the country's leading experts in the design of semiconductor power rectifiers. His work on hard brazed semiconductor devices results in units which withstand many thermal cycles without solder fatigue, thus expanding their usefulness. This work promises to give Westinghouse a unique position in this field. More recently, Dr. Green performed basic work on modular thermoelectric coolers.

Dr. Green is a responsible citizen in his community, as deacon, teacher of Sunday School, and lecturer from the pulpit of his church. He is very active in local engineering society affairs and has been adjunct professor at the University of Pittsburgh since 1958.

Honorable Mention Recipient Described

Dr. R. R. Johnson, of Phoenix, Ariz., also named for honorable mention, is 32 years old and a graduate of the University of Wisconsin in 1950. He received the M.S. degree from Yale University in 1951 and the Ph.D. degree from the California Institute of Technology in 1956. Dr. Johnson worked with the General Electric Company in the Summer of 1950 as a test engineer. During 1951-55, he was a research physicist with Hughes Aircraft Company and since then he has been with General Electric Company as manager of engineering in the computer department.

He discovered a new dynamic relationship in sequential logic which is used to simplify the static Boolean equations used in digital computers. He developed a digital principle for extracting complex roots of high order polynominals. He devised a new method for controlling machine tools using numerical data as an input. He has made other notable contributions and refinements for the Hughes Business Data Processing System and the ERMA computer currently in use by the Bank of America. He has a half dozen patents for inventions in the computer field. Currently, he manages the work of several hundred engineers and scientists in the field of electronic computer development, design, and application.

Dr. Johnson has helped to establish a summer counseling service for the Exploratory Boy Scout Program of the Palo Alto Boy Scouts' Council. He has organized and led small groups of young people in hiking and mountain climbing expeditions in the Sierra Mountains. He is a member of the Phoenix Chamber of Commerce and is very active in professional societies on the west coast.

Contributed to Guidance Technology

T. H. Thompson of Basking Ridge, N. J., another honorable mention recipient, is 32 years old and a graduate of the University of Texas in 1951. He received the M.S. degree in 1952 from the same university. Since graduation, Mr. Thompson has been employed by Bell Telephone Laboratories in Whippany, N. J. He worked in system engineering on a classified underwater sound project. More recently, he has been directly concerned with the development of Command Guidance Systems for the Titan ICBM and for Thor-Able, Tiros, and Delta Space Vehicles. He has made outstanding contributions to guidance technology. His ability to channel the best efforts of his subordinates and colleagues toward attainment of goals is a rare asset. He has also excelled in training personnel in new techniques and is currently preparing to teach a course in Missile Guidance.

Mr. Thompson is presently deacon, chairman of Stewardship Committee, chairman of Gifts and Memorials Committee, and superintendent of the Junior High Department of Basking Ridge Presbyterian Church. He has been assistant scoutmaster.

The Eta Kappa Nu recognition of outstanding young electrical engineers is intended to emphasize among electrical engineers that their service to mankind is manifested not only by achievements in purely technical pursuits but in a variety of ways. It holds that an education based upon the acquisition of technical knowledge and the development of logical methods of thinking should fit the engineer to achieve a substantial degree of success in many lines of endeavor. Eligible for the award is any man who on May 1

of each year has been graduated not more than 10 years from a regular course in electrical engineering from an American college or university and who is not more than 35 years of age. Selection is made on the basis of the candidate's record of achievement in his chosen work; in his service in behalf of his community, state, or nation; in his cultural or aesthetic development; and for his professional activities.

Eta Kappa Nu, the sponsor of the annual award, is the national electrical engineering honor society founded at the University of Illinois in 1904. The organization has more than 30,000 members, 82 college chapters, and 12 alumni chapters in the principal cities of the United States.

Selection of this year's recognition winner and honorable mention recipients was made by a Jury of Award.

Award Organization Committee Named

To assist the Jury of Award in their deliberations, the records of nominees are read and evaluated by the Society's Award Organization Committee. This group obtains references and other supporting data of use to the Jury of Award in the final judging. Every effort is made to secure nominations on a nationwide basis, and this year the 60 records of candidates represent all the geographical areas of major engineering activity in the country. The Award Organization Committee membership for 1960, under the chairmanship of W. B. Groth, included Robin Beach, Larry Dwon, J. E. Farley, N. S. Hibshman, C. T. Koerner, E. S. Lee, B. F. Lewis, J. M. Monstream, J. H. Craig, J. H. Mulligan, Jr., E. E. Schuster, and R. I. Wilkinson.

Irwin Gooen

HALL OF FAME for Great Americans, the national shrine is located on New York University's campus in the Bronx at University Heights. Its Greco-Roman semicircular colonnade winds for a quarter of a mile along high ground that overlooks the Harlem and Hudson river valleys and faces the New Jersey Palisades. To date, 85 persons from many fields of endeavor have been memorialized here in bronze.

Bronze Bust of Edison To Appear in NYU's Hall of Fame for Great Americans

THOMAS ALVA EDISON (HM '28) has been chosen as a winner in the 13th quinquennial election of the Hall of Fame for Great Americans. The announcement was made by Dr. R. W. Sockman, director of the national shrine at New York University (NYU), during a recent dinner attended by members of the Hall of Fame's College of Electors.

The late Mr. Edison, inventor of the first commercially practical incandescent electric lamp and other electrical devices, received 108 votes, while only 72 votes were required for election.

To qualify for election to the Hall of Fame, the candidate must have been a citizen of the United States and must have been dead at least 25 years before an election. Winners are enshrined in bronze busts in the open-air colonnade of the Hall of Fame, which is located on high ground at the University Heights campus of NYU in the Bronx. The shrine overlooks the Harlem and Hudson River valleys and the New Jersey Palisades.

His Early Life Described

Born in Milan, Ohio, in 1847, Mr. Edison had only 3 months of formal schooling, that in Port Huron, Mich., in 1854. While a young boy, he worked as a newsboy on the Grand Trunk Railroad and later as a telegraph operator in various cities.

His first inventions were the transmitter and receiver for the automatic telegraph, the quadruplex system of transmitting four simultaneous messages, and an improved stock-ticker system. He perfected many of his inventions at shops in Newark, Menlo Park, and West Orange, N. J.

Mr. Edison invented a carbon telephone transmitter in 1877 and a phonograph in 1878. But he is probably best known by posterity as the man who developed, in 1879, the first commercially practical incandescent lamp, or the electric light bulb. With that invention, he produced a complete system for the distribution of electricity for light and power, including generators, motors, light sockets, junction boxes, safety fuses, underground conductors, and other devices. In 1881, the sys-

Cleveland Section Holds Panel Talk

PARTICIPATING in a panel discussion at the Cleveland Section's October meeting were *(left to right)* W. J. Barrett, AIEE past president; W. H. Chase, moderator, AIEE District 14 vice-president, and L. A. Chacey, executive director of the Ohio Society of Professional Engineers. On the panel, but absent from the photograph, was W. H. Larkin of the American Society of Mechanical Engineers' Council. The subject of the panel discussion was "Achievement of Unity within the Engineering Profession."

tem was put to work in the Pearl Street plant in New York City. This was the first central electric light power plant in the world.

Recognized as Pioneering Inventor

In 1880, Mr. Edison built and operated an experimental electric railroad. He also developed the kinetoscope or "peep-show" machine and demonstrated experimentally the synchronization of moving pictures and sound. Talking pictures were based on the latter work.

During World War I, Mr. Edison helped develop the manufacture in the United States of chemicals that were previously imported. He was appointed head of the U. S. Navy Consulting Board, and worked on ship defenses against torpedoes and mines. He also worked on producing synthetic rubber from plants, principally goldenrod.

Thomas Edison held more than 1,300 United States and foreign patents.

Before his death in 1931, he had been a John Fritz Medalist (1908), an honorary AIEE member (1928), and an AIEE member (AM '84, M '84, Member for Life).

EIC Is Host to ECPD at Council's 28th Annual Meeting

The Engineering Institute of Canada (EIC) was host to the Engineers' Council for Professional Development (ECPD) for its 28th Annual Meeting in Montreal, Que., Canada, October 3-4. There were 220 registrants at the meeting from the United States, Canada, and Mexico.

In addition to meetings of all standing committees and reports of their work, there were featured talks by Dean W. L. Everitt, of the University of Illinois, and president of ECPD; Col. L. F. Grant, past-president of ECPD and of the Engineering Institute of Canada, and Alan Jarvis, editor of "Canadian Art," and a well-known Canadian television and radio speaker.

Forum talks and discussions covered the work of the Committees on Education and Accreditation, Student Development, Recognition, and Development of Young Engineers.

A highlight of the meeting was the presentation by the Committee on the Development of Young Engineers of a new booklet, whose subject was: "Citizenship and Participation in Public Affairs." This is an attractive 24-page booklet designed to interest young engineers in taking an active part in community and other public affairs. It is introduced by a Manifesto by former President Herbert Hoover urging engineers to assume their rights and duties as citizens. Practical suggestions are given for individual participation in community activities and in politics. Group action on the part of engineers in Detroit is described.

The booklet is available from ECPD, 29 W. 39th St., New York 18, N.Y., for 25¢ per copy. Discounts are available for quantity orders. Industrial leaders are ordering the book for distribution to their younger engineers.

Donation Made to UEC Building Fund

CONTRIBUTION of a $500 check for the United Engineering Center (UEC) Building Fund has been made by the West Virginia Section, AIEE. C. M. Hunt (*second from left*), chairman of the 1960 East Central and Allegheny-Ohio Valley District Meeting, is shown presenting the check to B. W. Whittington (*third from left*), Section chairman. Looking on are: M. H. W. Illing (*left*), Section vice-chairman, and L. M. Roth (*right*), immediate past chairman. The check represented a surplus from District Meeting and Section funds.

Engineering Honor Society Celebrates Diamond Anniversary

ONE hundred and two collegiate chapters and several alumnus chapters of the Tau Beta Pi Association, Inc., the national engineering honor society, were represented at Tau Beta Pi's Diamond Anniversary Convention, held at Lehigh University, Bethlehem, Pa., on October 13-15.

The meeting was the association's 55th Convention, and it was staged at the site of Tau Beta Pi's founding in 1885. The Pennsylvania Alpha chapter at Lehigh was official host, assisted by the Lehigh Valley alumnus chapter of the association in planning and conducting the 3-day session.

The convention was also attended by the association's national officers and by alumnus and faculty members from numerous chapters. Lehigh's University Center and the Hotel Bethlehem were the headquarters for the meeting.

Convention Program Given

The convention program consisted of 4 business meetings, several specially arranged panel discussion sessions, 2 banquet programs of particular interest, a convention luncheon speaker of international renown, and a 75th anniversary ceremony where a monument in the form of a large bronze Bent, a replica of the Tau Beta Pi key, was dedicated on the Lehigh campus.

Plans for the national meeting were made under the general direction of J. A. Nolen, Jr., president of Pennsylvania Alpha, and S. T. Harleman, president of the Lehigh Valley alumnus chapter. They had the assistance of the members, officers, and advisors of their chapters. P. H. Robbins, director of fellowships for Tau Beta Pi, and the executive director of the National Society of Professional Engineers, Washington, D. C., served as chairman of the convention business meetings.

Speakers Named

The main speakers on the welcoming luncheon program on October 13 were Dr. E. K. Smiley, vice-president of Lehigh University, and Dean L. V. Bewley (AM '27, F '47) of Lehigh's College of Engineering.

The convention granted four new chapters of Tau Beta Pi to local engineering honor societies at the University of Dayton, Dayton, Ohio; the University of Florida, Gainesville, Fla.; the University of Notre Dame, South Bend, Ind.; and Villanova University, Villanova, Pa. These groups had submitted petitions for charters last winter, and their new chapters will be installed this coming winter as the association's 104th, 105th, 106th, and 107th undergraduate groups.

The Diamond Anniversary dinner of the convention was held October 13, and the program was presided over by R. C.

Matthews, secretary-treasurer emeritus of Tau Beta Pi, who served the association as a national officer from 1905 until his retirement in 1947. Speakers were the past presidents of Tau Beta Pi, who traced the history of the organization by relating important developments during their terms of office. Mr. Matthews filled in the time gaps between presidencies in a style that is famous among members of the association. Past presidents in attendance at the convention as special guests were L. E. Moore of Vero Beach, Fla., Prof. A. D. Moore (M '24, F '43) of the University of Michigan, Prof. Emeritus P. W. Ott of Oxnard, Calif., and E. R. Moore (M '40, F '58) of the Detroit Edison Company, Detroit, Mich. Only two other past presidents are still living, the association's first, in 1895-96, Dr. H. B. Evans of Merion, Pa., and C. H. Spencer of Washington, D. C.

The Bent monument was dedicated on October 13 in an impressive ceremony which featured as speakers two sons and two grandsons of Tau Beta Pi's founder, Dr. E. H. Williams, Jr., who died in 1933; H. R. Lee of Scarsdale, N.Y., first editor of Tau Beta Pi's national magazine, in 1906-07; and Dean Bewley and Mr. Nolen of Lehigh University. J. W. Foster of the Lehigh Valley alumnus chapter, which donated the Bent monument, presided at the ceremony.

The founder's sons who attended the convention as special guests were E. H. Williams, III, of Woodstock, Vt., and Wentworth Williams of Groton, Mass. His grandsons were Dr. D. M. Parke of Landenberg, Pa., and Dr. N. G. Parke, III, of Carlisle, Mass.

The convention luncheon speaker on October 14 was Dr. W. F. G. Swann, director emeritus of the Bartol Foundation of the Franklin Institute, Swarthmore, Pa., whose stimulating address was titled "Science and the Engineer." Tau Beta Pi's vice-president, A. W. Consoer, of the Chicago consulting engineering firm of Consoer, Townsend and Associates, presided over the convention luncheon program.

Initiation and Banquet Held

A major event of the convention was the initiation and banquet on Friday evening, October 14. The initiation ceremony was conducted by a group of former Tau Beta Pi officers led by Secretary Emeritus Matthews. The ceremony brought into membership in the association 19 students of Lehigh University, 8 students of Lafayette College, Easton, Pa., where the Pennsylvania Epsilon chapter is located, Dr. W. F. G. Swann for the Pennsylvania Delta chapter at the University of Pennsylvania, and four alumni, Dr. R. T. Gallagher, R. A. Harrier, and Dr. Fazil Erdogan, of the Lehigh University staff, and Dr. N. G. Parke, III, of the Parke Mathematical Laboratories.

The major address on the initiation banquet program was delivered by Dr. R. D. Stout, dean of Lehigh University's graduate school. It was titled "Engineering, Education, and Everything." Another feature of the program was the announcement and presentation by Vice-President Consoer of the winners of the Outstanding Chapter Awards for 1959-60. Top prize in this competition went to the Maryland Beta chapter at the University of Maryland, and honorable mentions were given to Louisiana Gamma at Louisiana Polytechnic Institute, New York Kappa at the University of Rochester, and Texas Alpha at the University of Texas. Master of ceremonies for the initiation banquet was S. T. Harleman, to whom was given a special plaque in appreciation for his many services to Tau Beta Pi during a period of 60 years since his initiation as a student at Lehigh in 1900.

Professional Development Discussed

A panel discussion of unusual interest at the Lehigh convention was held on October 15. Arranged and presided over by Dr. G. G. Lamb of Tau Beta Pi's Executive Council, it was directed to the theme "Professional Development for Young Engineers." Speakers were Dean Emeritus N. W. Dougherty of the University of Tennessee, Associate Dean Cornelius Wandmacher of the University of Cincinnati, Vice-President A. W. Consoer, Dr. A. S. Foust of Lehigh University, and Prof. F. R. E. Crossley of Yale University. All the speakers stressed the importance of integrity, the relationships of confidence, awareness of the social implications of engineering, the exercise of reasoned judgment, and continuing education.

The convention voted to hold the 1961 national meeting in October in Cincinnati, Ohio, with the Ohio Beta chapter at the University of Cincinnati as host. The 1962 Convention will be held at Long Beach, Calif., and serving as hosts will be the three undergraduate chapters and the Southern California alumnus chapter, all in the Los Angeles area.

Valuable features of Tau Beta Pi conventions are the chapter-work discussions and the exhibits at which ideas for school and community service projects and chapter administration are exchanged by the delegates, most of whom are presidents of their local groups. This year's discussions in that field were again led by students under the general direction of Dr. J. R. Young of New Mexico State University, chapter co-ordinator for the association.

The chapter co-ordination discussions again included the presentation of ideas and experiences in the area of alumnus-undergraduate chapter relations. Mr. Harleman of the Lehigh Valley alumnus chapter, A. B. Cristy and L. McGurk of the Rochester alumnus chapter, and L. T. Monson and H. F. McGaffey of the Southern California alumnus chapter, who is also master of rituals for Tau Beta Pi, discussed the co-operative work their groups have recently done with the undergraduate chapters near them. This discussion was arranged by M. V. Burggraaf (AM '50), Tau Beta Pi's alumni representative.

Tau Beta Pi is a national engineering honor society now comprising 103 undergraduate chapters, 29 alumnus chapters, and more than 106,000 initiated members. Students are elected to membership by the chapters from the top 20%, scholastically, of their engineering classes on the

Fellow Certificate Presented

FIRST Maine Section member to achieve the Fellow grade since the organization of the AIEE Section on July 8, 1955, Prof. W. J. Creamer (center), head of electrical engineering at the University of Maine, received the Fellow certificate at a recent meeting. Pictured are: (left to right) H. A. Crosby; W. W. Turner, past chairman of the Section; Prof. Creamer; F. S. Bacon, Jr., AIEE District 12 vice-president; and G. F. Hart, Section chairman.

basis of character and service to their colleges. Alumni may be elected on the basis of their eminent achievements in the engineering profession.

Tau Beta Pi's present Executive Council, or board of directors, includes five alumnus members who live in or near Chicago. President of the association is Dr. D. A. Dahlstrom, director of research and vice-president of the Eimco Corporation, Palatine, Ill., who was out of the country on business during the 75th Anniversary convention. Vice-president is A. W. Consoer; and councillors are Dean R. G. Owens of Illinois Institute of Technology, Dr. G. G. Lamb of Northwestern University, and L. C. Rogers of the Bates and Rogers Construction Company, Chicago. R. H. Nagel is secretary-treasurer and editor of Tau Beta Pi, and the national headquarters of the association are located at the University of Tennessee, Knoxville, Tenn.

Lehigh Valley Section, AIEE and PSPE Hold Panel Discussion

"Engineers, are you for Unity? If not, why not?" This was the subject of a panel discussion meeting held September 16 at the Irem Temple Country Club, Dallas, Pa. and sponsored by the Lehigh Valley Section, AIEE, and the Luzerne County Chapter of the Pennsylvania Society of Professional Engineers (PSPE).

The program planners were: A. J. Fladd, chairman of the Lehigh Valley Sections Committee on Professional Development, and secretary of the Luzerne County Chapter of PSPE; Dr. L. T. Buckman, past president of the Pennsylvania Medical Society; Attorney H. L. Winkler, public relations chairman of the Wilkes-Barre Law and Library Association; and W. W. Middleton, Lehigh Valley Section, AIEE.

Mr. Middleton served as moderator of the panel discussion. Panel members were Dr. Buckman, Attorney Winkler, and C. T. Pearce, past president of AIEE District 2, and at present a member of the AIEE Task Force on Unity in the Engineering Profession.

Following the panel discussion, several plans for unity were proposed and explained, and the 83 AIEE and PSPE members were asked to vote for the plan they preferred.

Hillerman

RESPONSIBLE for the success of the 1960 Petroleum Industry Conference held September 25-29 in Oklahoma City, Okla., were these members of the 1959-60 Petroleum Industry Committee, AIEE, as follows: (*seated, left to right*) Vice-Chairman, W. H. Dickinson, Esso Research and Engineering Company; Chairman, M. A. Hyde, Westinghouse Electric Corporation; AIEE Technical Activities, R. S. Gardner, AIEE Headquarters; Chairman of Transportation Subcommittee, C. D. Catt, El Paso Natural Gas Company; (*standing, left to right*) Secretary, Tom Backman, Plantation Pipe Line Company; Local Conference Chairman, R. J. Thompson, Carnahan and Thompson, consulting engineers; Chairman of Production Subcommittee, W. E. Withers, Sun Oil Company; and Chairman of Refining Subcommittee, George St. Onge, Esso Research and Engineering Company.

Availability of Energy Studied at Petroleum Conference

"The theme chosen for this 7th Annual Electrical Conference—'Electrical Technology Paces Petroleum Progress'—is an excellent one.

Here, wrapped up in one neat sentence, is a truism which reflects the past and present relationship of the electrical and petroleum industries, and at the same time, provides a challenge to our partnership to achieve even greater accomplishments in future years." These words from the keynote address by D. A. McGee, president and director, Kerr-McGee Oil Industries, Inc., marked the beginning of the 1960 Petroleum Industry conference held September 25-29 in Oklahoma City, Okla.

The 3-day conference was attended by 385 engineers from almost every state in the Union, as well as Hamilton and Ontario, Canada, and Caracas, Venezuela. A total of 25 technical papers were presented to satisfy the needs of the three specific petroleum groups—Refining, Production, and Transportation. The conference provided engineers with information on recent developments and progress in the industry through the use of electricity for power, communication, control, and automation.

In recognition of his work and assistance to the Petroleum Industry Committee, R. S. Gardner of AIEE Headquarters was made an Indian Chief in a colorful ceremony during the conference. His Indian name is Chief Chanawye.

The new Petroleum Industry Committee chairman, W. H. Dickinson, Esso Research and Engineering Company, announced that the 1961 Conference will be held in New Orleans, La. In addition to Mr. Dickinson, new officers for 1960-61 will be: Vice-Chairman, L. B. Eddy, consulting engineer, Mount Prospect, Ill.; Chairman of Transportation Subcommittee, J. J. Sonnier, Shell Pipe Line Corporation, Houston, Texas; Chairman of Production Subcommittee, W. E. Withers, Sun Oil Company, Beaumont, Texas; Chairman of Refining Subcommittee, George St. Onge, Esso Research and Engineering Company, Madison, N. J., and Secretary, E. B. Turner, General Electric Company, Pasadena, Texas.

Ace Hoffman Studios

UNITY for engineers was the topic of a panel discussion held recently at a meeting of the Lehigh Valley Section, AIEE. Shown planning the program are: (*left to right*) A. J. Fladd, Dr. L. T. Buckman, Attorney H. L. Winkler, and W. W. Middleton.

AIEE FELLOWS ELECTED

Rinehart Marsden

I. M. Ellestad

Ohio Bell Telephone Co.

L. J. Shaffer

***Irwin Martin Ellestad** (AM '24, M '46), transmission design engineer, Northwestern Bell Telephone Company, Omaha, Nebr., has been transferred to the grade of Fellow in the AIEE ". . . for contributions to the solution of fundamental engineering problems of inductive co-ordination and telephone transmission." He was born December 5, 1895, in Lanesboro, Minn., and received the B. S. and electrical engineering degrees in 1922 and 1923, respectively, from the University of Minnesota. Commencing in 1923, Mr. Ellestad was in the plant department of the Northwestern Bell Telephone Company in Minneapolis, Minn., and in 1926 was transferred to the chief engineer's department in Omaha. During 1928-33, he was in New York with the Transmission Section in the department of operation and engineering of the American Telephone and Telegraph Company. Since 1936, Mr. Ellestad has been with the Nebraska Area chief engineer's department of Northwestern Bell Telephone in Omaha. He is a registered professional engineer in the State of Nebraska, and a member of Sigma Xi. Mr. Ellestad served as District 6 vice-president (1947-49), Nebraska Section secretary (1942-49), AIEE District 6 secretary (1939-41), and Nebraska Section chairman (1938-39). Mr. Ellestad is a member of the AIEE Wire Communication Systems Committee (1954-61).

***Lee Jay Shaffer** (AM '38, M '47), general engineering supervisor—buildings, Northeastern Area of the Ohio Bell Telephone Company, Cleveland, Ohio, has been transferred to the grade of Fellow in the AIEE" . . . for contributions to the development of personnel for communications engineering." Mr. Shaffer was born in Akron, Ohio, on September 27, 1904. He was employed by Ohio Bell in Akron in 1927 as a lineman, and transferred to the Plant Engineering Division as a fieldman on toll line engineering and inspection. In 1928, he was associated with the Packard Electric Company, Warren, Ohio, as time study and efficiency man under the Bedeaux Plan. He was re-employed in 1928 by Ohio Bell in Toledo, Ohio, as assistant engineer, and subsequently transferred to Cleveland as instructor on technical communications subjects. During 1933-35, he was engaged in intercity facility testing and circuit trouble analysis at Canton, Ohio. Mr. Shaffer returned to Cleveland as general instructor in early 1935 with full responsibility for training course preparation and technical instruction of plant department personnel. He was later promoted to engineer in the Plant Extension Division of the general engineering department. He was ordered to Fort Monmouth, N. J., in 1941 by the War Department and held numerous responsible training assignments prior to becoming a colonel in the Signal Corps as assistant commandant of the Eastern Signal Corps School. He became signal officer of the Alaskan Department for 10 months. Upon his release from active duty in 1946, he returned to Ohio Bell and was promoted to transmission development engineer. He subsequently became supervisor of plant training, and in 1949, toll superintendent. In 1952, he became operating staff engineer, and in 1955, general engineering supervisor. He returned to the general engineering department in 1957, and in 1958 became general engineering supervisor—building. He was awarded the Legion of Merit for his military accomplishments. He is a member of Sigma Tau and Scabbard and Blade, a registered professional engineer in the State of Ohio, and a member of the Cleveland Engineering Society. Mr. Shaffer has served on the AIEE Wire Communication Systems Committee (1950-60) and Management Committee (1956-57).

*Transfer to the grade of Fellow was approved at the Board of Directors meeting on September 20, 1960.

AIEE PERSONALITIES

D. J. Angus (AM '09, F '45, Member for Life), a founder of the Esterline-Angus Instruments Division of the Dyson Corporation, New York, N. Y., has retired from his position as president of the division after 50 years service. Mr. Angus will continue to serve the company as a consultant.

L. S. Armstrong (AM '57) has been named Northeast Region manager of the A. B. Chance Company. In his new capacity, Mr. Armstrong will be in charge of all Chance marketing activities for an 11-state area. He was formerly district manager of the Baltimore-Washington area for the company.

N. K. Barr (AM '44, M '47) has been appointed technical manager of the Electrical Conductor Division, Kaiser Aluminum & Chemical Sales, Inc. He was formerly chief engineer of the division. **J. B. Roche** (AM '49, M '59) has been named chief engineer for overhead conductor products, and **R. S. Keith** (AM '50) has become chief engineer for insulated products. Mr. Roche has held several positions for Kaiser Alumnium which have dealt with conductor design and application. Mr. Keith was formerly assistant engineer, insulated products.

A. S. Basil (M '46) has been named president of the Rockbestos Wire & Cable Company, a division of Cerro de Pasco Corporation. Prior to his appointment as president, Mr. Basil was vice-president and general manager.

Herman Epstein (AM '48, M '56), former vice-president and director of engineering for Tele-Dynamics, Inc., in Philadelphia, Pa., has been named president of Omnitronics, Inc., a Philadelphia-based subsidiary of Borg-Warner Corporation. Mr. Epstein has served on the AIEE Solid State Devices Committee (1955-61).

K. V. Farmer (M '21) has retired from his position of vice-president of the Canadian Ohio Brass Company, Ltd. Mr. Farmer has been affiliated with the Ohio Brass Company since 1924, first at the Barberton, Ohio, plant, and then at the home office in Mansfield, Ohio. In 1931, he was named manager and director of Canadian Ohio Brass in Niagara Falls, Ont., and in 1946, vice-president and director of Canadian Ohio Brass. He served as vice-president and managing director of the company during 1957-59. He was elected to the board of directors of the Ohio Brass Company in 1950 and will retain his position on the board. A veteran member of the Canadian Electrical Manufacturers Association, Mr. Farmer has held the offices of director, vice-president, and president of the association.

G. E. Frederick (AM '49) has been appointed vice-president and technical director for the Frederick Research Corporation, Wheaton, Md. He joined the Frederick Research staff on August 20.

W. S. Gerrie (AM '52) has been appointed general sales manager of the Telautovision, Olivetti Teleprinter, Telescriber,

and Hogan Commercial Faximile divisions of the TELautograph Corporation. Mr. Gerrie formerly had his own management consultation firm in Los Angeles, Calif.

John Gibb (AM '52) has been named mideastern division manager of brush and railroad products for National Carbon Company, Division of Union Carbide Corporation, with headquarters in Pittsburgh, Pa. Since 1957, he had been a carbon products sales representative in Dayton, Ohio.

F. W. Godsey, Jr. (AM '30, F '45), president of Electronic Communications, Inc., St. Petersburgh, Fla., since 1956, has been named for inclusion in the second and most recently published volume of "American Men of Science," the "Who's Who" of the nation's physical sciences. **E. N. Dingley, Jr.** (M '56, F '57), principal engineering scientist of Electronic Communications' Scientific Advisory Group, was selected for inclusion in the first volume which covered letters A-E of the alphabet.

F. B. Hall (AM '49, M '59) has been appointed an associate electrical engineer in the Reactor Engineering Division of Argonne National Laboratory, Argonne, Ill. In his new position, he will work on instrumentation for the Experimental Breeder Reactor II now being built at Argonne's Idaho Division near Idaho Falls, Idaho. Since 1959, he had been senior electrical engineer at Three E in Melrose Park, Ill.

J. L. Haraburda, Jr. (AM '49) has been appointed a plant engineer in the Plant Engineering Division of Argonne National Laboratory, Argonne, Ill. In his new position, he will furnish and co-ordinate electrical engineering designs, services, and estimates between various scientific divisions throughout the laboratory and the Plant Engineering Division. He was formerly affiliated with Holabird and Root, Chicago, Ill., as electrical engineer and squad leader.

H. H. Heidrick (AM '55) of Belmont, Calif., has been named public utilities consulting engineer for Wilsey, Ham & Blair. In his new post, Mr. Heidrick will handle utility rate and valuation studies for clients served by the firm from Millbrae, Calif., and Los Angeles, Calif. Mr. Heidrick previously served the California State Public Utilities Commission at San Francisco, Calif.

W. B. Helms (AM '49) has been appointed to the position of manager of the Giannini Controls Corporation's Pasadena-based Transducer Division. Mr. Helms was formerly assistant manager of the Transducer Division.

D. R. Hull (M '48) has been elected corporate executive vice-president of Hoffman Electronics Corporation by its board of directors. In his newly created position, Mr. Hull will have direct responsibility for the operation of Hoffman's Military Products Division and co-ordination of activities of the company's Santa Barbara, Calif., Science Center with other corporate divisions. Prior to his new position, Mr. Hull was for 10 years vice-president and general manager of equipment operations for Raytheon Company.

J. N. Hutson (AM '60) has been appointed North Central regional manager of the Federal Pacific Electric Company. Previously, Mr. Hutson was the Birmingham, Ala., district sales manager.

L. F. Jones (M '57) has joined United Aircraft Corporation's Norden Division as chief—digital group in the engineering department. In this position, Dr. Jones will direct Norden's scientific research and development programs in digital devices and data-handling systems. He came to Norden from Westinghouse Corporation's Air Arm Division at Baltimore, Md., where he had been advisory engineer in charge of the digital computer group.

A. E. Kilgour (AM '39, M '47), who has been on special assignment with C Stellarator Associates, Inc., at Princeton, N. J., has joined Allis-Chalmers power systems department in Milwaukee, Wis.

Victor Kostuck (AM '48) has been elected vice-president of Leach Corporation, Compton, Calif. Mr. Kostuck joined the firm 6½ years ago as a divisional manager for the Pacific Northwest states. He had been serving as assistant to the president, and in recent months had responsibility of co-ordinating sales and operations of the five Leach divisions as well as the overseas marketing subsidiary, Leach International, S. A.

M. D. Lockwood (AM '45) has been appointed vice-president of Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Neck, N. Y. Mr. Lockwood had been manager of the company's Surface Armament Division since 1957.

E. B. Noel (AM '45, M '52), manager, incandescent lamp design engineering, General Electric Company, Cleveland, Ohio, has been elected to Fellow grade in the Illuminating Engineering Society for significant developments in electric lamps.

G. G. Quarles (AM '45, M '56) has been appointed to the new post of director for long-range military planning of the Bendix Corporation. Dr. Quarles, who has been chief scientific adviser of the U. S. Army Corps of Engineers, will assist in the establishment of a corporate plan to meet the need for future defense and government requirements. In addition, Dr. Quarles will establish a technique for evaluating long-range trends in weapons systems and all government-support systems.

J. R. Topper (AM '53) has been appointed product sales manager for industrial and military tubes produced by the General Electric Company's receiving tube department, Owensboro, Ky. He joined General Electric in 1952, and since early this year was sales manager for developmental products, industrial and military receiving tubes.

H. K. Weiss (M '50) has been named manager of military systems planning for the technical staff at Ford Motor Company's Aeronutronic Division, Newport Beach, Calif. Mr. Weiss was formerly manager of advanced systems development for Aeronutronic's Weapons Systems Operations.

OBITUARIES

Walter R. G. Baker (AM '19, M '41, F '47, Member for Life), retired General Electric Company vice-president, died October 30. His 40-year business career at General Electric terminated in 1957, and at the time of his death he was vice-president in charge of research at Syracuse University. A native of Lockport, N. Y., he was born November 30, 1892, and was educated at Union College from which he received the E.E. and M.E. degrees in 1916 and 1918, respectively, and the honorary D.S. degree in 1935. In 1917, he joined the General Electric Company's Schenectady, N. Y., laboratory, and in 1918, began his first work in radio, developing and testing apparatus for aircraft, submarines, captive balloons, torpedo boats, destroyers, and battleships. When General Electric established a radio department in 1920, Dr. Baker was appointed designing engineer in charge of transmitters. He was assigned the responsibility of designing all radio products in 1924, and in 1926 assumed full charge of development, design, and production. Pioneer broadcasting stations were designed in Schenectady; Denver, Colo., and Oakland, Calif., under his supervision, and he planned and built the south Schenectady radio development laboratory. During 1930-35, Mr. Baker was vice-president and general manager of the Radio Corporation of America Victor radio plant at Camden, N. J. He returned to General Electric in 1935 as manager, radio and television department, in Bridgeport, Conn., and Schenectady. Dr. Baker became a vice-president in 1941, heading the Electronics Division. In 1956, when the Electronics Division was reorganized into the Defense Electronics Division, the Industrial Electronics Division, and the Electronic Components Division, Dr. Baker was named consultant to C. W. LaPierre, executive vice-president of the company's electronic, atomic, and defense systems group. He was honored by both the Army and Navy for his contributions during

General Electric Company

W. R. G. Baker

World War II. After the war, Dr. Baker specialized on the development and production of television and FM equipment. Television Station WRGB in Schenectady uses his initials. He was chairman of the National Television Systems Committee, which recommended standards for black and white television which were adopted by the Federal Communications Commission. He also was chairman of another committee that recommended color telecasting standards accepted by the Federal Communications Commission. Dr. Baker held the Medal of Honor of the Institute of Radio Engineers. He served on the following AIEE Committees: Biographies and Talking Motion Pictures (1933-34, 1937-41); Postwar Planning (1943-45); Award of Institute Prizes (1947-52); Electronics (1945-57, chairman 1945-47); Standards (1945-47); Technical Program (1945-48); Communication and Science Co-ordinating (1947-48, chairman); and Planning and Co-ordination (1947-50).

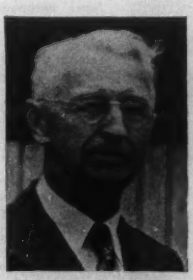
Cyril Rex Bloom (AM '38), a supervisory engineer in the steam turbine department of Allis-Chalmers Manufacturing Company, Milwaukee, Wis., died September 26 at the age of 45. Mr. Bloom was born July 18, 1915, in Glen Hope, Pa. He joined Allis-Chalmers in 1937 after graduation from Pennsylvania State College with the degree in electrical engineering. After completing the company's training course for graduate engineers, he became associated with the steam turbine department in 1939. At the time of his death, he was in charge of sales promotion and publicity for the department. Mr. Bloom was a registered professional engineer in the State of Wisconsin.

Samuel Hawks Caldwell (AM '27), professor of electrical engineering, Massachusetts Institute of Technology (MIT), Cambridge, Mass., died October 12 at the age of 56. Dr. Caldwell was credited with building the world's first large-scale analog computer. He was born January 15, 1904, in Philadelphia, Pa. In 1925, he received the B.S. degree in electrical engineering from MIT, in 1926 he was awarded the M.S. degree, and later the Sc.D. degree. Dr. Caldwell served on the AIEE Computing Devices Committee (1947-52) and Instruments and Measurements Committee (1948-49).

George Nettelton Crosthwait (AM '44, M '50), an engineer with the Texas Electric Service Company, Forth Worth, Texas, for 30 years, died recently at the age of 58. He was born August 3, 1902, in Dallas, Texas, and received his degree in electrical engineering from Cornell University. Mr. Crosthwait came to Fort Worth 4 years ago after serving the company at Big Spring, Texas, for 7 years, at Wichita Falls, Texas, for 15 years, and at Dallas, 3 years. He was superintendent of the company's Transmission Division at Wichita Falls.

Kilshaw McHenry Irwin (M '46), vice-president in charge of engineering for the Philadelphia Electric Company, Philadelphia, Pa., died October 3 at the age of 67. He was born September 19, 1893, in Waukesha, Wis., and graduated from the Sheffield Scientific School of Yale University in 1915 with the Ph.B. degree. That year, he was employed by the B. F. Sturtevant Company, Hyde Park, Mass., as assistant to the research engineer. In 1916, he became assistant to the station betterment engineer of Stone & Webster Engineering Corporation, Boston, Mass., and in 1918, was employed by Perry Barker, consulting engineer, Boston. He served as chief machinist's mate, U. S. Naval Reserve Force, Philadelphia, Pa., in 1918-19. For the next 8 years, he was employed by the United Gas Improvement Company as assistant to the electrical engineer, and in 1927, he was appointed mechanical engineer. During World War II, Mr. Irwin was executive director of the London Staff, Public Utility Commission of the Combined Production and Resources Board, and in this capacity made contributions to the restoration of utility service in northwest Europe. In 1931, he took the position of assistant to the vice-president in charge of engineering of the Philadelphia Electric Company, and in 1945, became manager of the engineering department. Mr. Irwin, who was named Philadelphia "engineer of the year" by the engineering societies in that area, in 1958, was a vice-president of Atomic Development Associates, Inc., which is currently building a reactor near Detroit, Mich. He had been a member of the U. S. National Committee, World Power Conference, since 1955, and chairman of the committee during 1958-60. He was a Fellow of the American Society of Mechanical Engineers, and a member of the Association of Edison Illuminating Companies, the Edison Electric Institute, the Pennsylvania Electric Association, and the Engineers Club of Philadelphia. He was also a member of Tau Beta Pi, the Princeton University Advisory Council of the department of mechanical engineering, and of the Society of American Military Engineers.

Joseph Nelsen Kelman (AM '08, M '26, F '31, Member for Life), pioneer in the field of power circuit breakers, died September 24. Mr. Kelman built his first successful oil circuit breaker in 1901, and in 1906 was engaged in the manufacture of high voltage oil circuit breakers of his own design. In 1908, the Kelman Electric and Manufacturing Company in Los Angeles, Calif., was incorporated, and Mr. Kelman was elected president and manager. The business he founded is now the Kelman Division of the I-T-E Circuit Breaker Company. He was born December 8, 1874, in Glenmorris, Ont., Canada. In 1900, the Stanley Electric Manufacturing Company sent him to California, where he installed generators in the Electra Plant of Standard Electric Company. The following year, he became division superintendent of the Bay Counties Power Company in charge of the operation and construction work in the Colgate and Marysville Division. He was employed by R. S. Masson in Los Angeles in 1903 as an engineer in charge of laying out and building the Kern River Power Company's 60,000-volt transmission line from Borel to Los Angeles. Later, he had charge of the electrical construction of the Mentone Power House and substations of the Pacific Light and Power Company. In 1904, he was appointed superintendent of the Kern River Power Company in charge of the operation and maintenance of the Borel Power House, transmission line, and main substation.



J. N. Kelman

Frank Ernest Saracino (AM '30, M '48), manager of the Mandel Lear Building, Chicago, Ill., and consulting engineer for Mandel Brothers, Inc., died recently. He previously was plant manager for the Manistee Salt Works in Manistee, Mich., and supervising engineer for the Chicago Housing Authority. Mr. Saracino was born July 11, 1906, in Chicago, Ill., and was educated at the Illinois Institute of Technology from which he received the B.S. degree in electrical engineering in 1932. He was a member of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and the American Society of Mechanical Engineers.

Harold E. Turner (AM '26, M '41), executive vice-president of the American Electric Power Service Corporation, New York, N. Y., died October 24 at the age of 58. Mr. Turner was responsible for the operating and commercial activities of the 7-state American Electric Power System. He had served previously as vice-president and general manager of the Ohio Power Company, an American Electric Power System operating company, with headquarters in Canton, Ohio. Mr. Turner was born January 29, 1902, in Bealton, Ont., Canada, and graduated from the University of Toronto in 1924 with the B.A.Sc. degree in electrical engineering. During 1924-26, he worked for the General Electric Company on testing, design, and general electrical engineering. Mr. Turner was employed by the American Gas and Electric Company and the American Gas and Electric Service Corporation in 1926-41 as assistant relay engineer, assistant to the electrical engineer, assistant to the chief engineer, and assistant to the vice-president and chief engineer. He joined the Ohio Power Company in 1941 as assistant general manager. Mr. Turner was a director of the parent American Electric Power Company and a vice-president and director of three subsidiaries. He was a founder and served as first president of the Ohio Electric Utility Institute. He was a past director of the Edison Electric Institute and a member of the National Society of Professional Engineers. Mr. Turner served on the AIEE Protective Devices Committee (1934-36).

OF CURRENT INTEREST

AMONG principal components in the mail-processing scheme at Providence, R. I.'s automated post office are facer-cancellers. Letters and cards are placed in proper "stamp down" position by a combination of photoelectric cells and inverting belts at a rate of 25,000 an hour. The "electric eye" system also determines whether stamp is on leading or following edge, separating mail on this basis for high-speed cancelling heads.

Project Turnkey—Automated Post Office in Operation

THE FIRST fully-automated post office in the United States—hailed by Postmaster General Arthur E. Summerfield as a "major landmark in the development of the American postal system"—was placed in official operation in Providence, R.I., recently.

The new postal facility is located on a 14.5-acre site in West River Industrial Park, minutes from the downtown Providence business section. Designated Project Turnkey, since, figuratively, it went into operation at the turn of a key, the post office was designed and constructed by Intelex Systems Inc., subsidiary of International Telephone and Telegraph Corporation. The Post Office Department holds a 20-year lease on the building with additional options.

CULLERS—"Raw" mail (letters, large envelopes, packages, hotel keys, etc.) is culled or separated at a rate of 25,000 pieces an hour, as it pours in a continuous stream onto first one, then another, and still another vibrating table. Packages and pieces of mail too large for processing are removed by conveyors for further separation. Letters or post cards arrive at a special stacker prior to facing and cancelling.

The new post office incorporates the latest in mail-handling machines and methods. It is made up of a work-floor totaling 123,000 square feet, and a 42-office mezzanine area of approximately 20,000 square feet. Loading platforms for trucks and railway cars contribute another 45,000 square feet to the facility. There is also a separate lubritorium for maintenance and servicing of the 130-truck Turnkey fleet.

The building is 420 feet long, 300 feet wide, and 55 feet high, big enough to accommodate two football fields beneath its distinctive clam-shell or "parabolic" roof. It is designed to handle the daily Providence-area mail volume—about 1.1 million pieces daily—and the anticipated 1977 volume of 2 million.

Situated in a section which is criss-crossed by major transportation arteries, the new post office will also speed mail for a strategic area of New England, embracing all of Rhode Island, southeastern Massachusetts, and the Cape Cod area. In addition to direct improvement of mail service for this wide geographic area, the post office will test the latest machines and equipment for eventual implementation in other post offices around the country, Mr. Summerfield said.

"It will be a major proving ground," the Postmaster General said, "for post offices of tomorrow, helping us break the age-old mail service bottlenecks."

Principal components in the mail-processing scheme at Turnkey are cullers, which segregate "raw" mail (letters, large envelopes, cards, packages, hotel keys, etc.) according to type and size; facer-cancellers, to position letters and cards for cancelling; and the mammoth sorters,

one type which separates letters to any of 300 destinations, and another which directs parcel-post mail to 31 outlets. Each of the six cullers and facer-cancellers processes 25,000 pieces of mail an hour. The letter sorter's capacity is 18,000 an hour for each of the 11 machines at Turnkey. The parcel-post sorter handles 4,800 packages each hour.

Control Tower Provides Check

Two men—scanning operations from a glass-enclosed tower 25 feet high—act as virtual "production managers" in Project Turnkey.

Information on the flow of mail is fed to the tower constantly through a complex signaling and monitoring system that displays the status of each unit of mail-processing machinery—and counts the mail, as well.

Thirteen consoles ring the tower interior, each telling of some aspect of the variegated activity going on below.

A system of colored lights allows the controller to communicate with supervisors at 19 receiving stations on the floor. Lights also tell the man in the tower when a machine or conveyor is available (yellow), running (green) not available or in emergency stop (both red).

By throwing switches in the tower, the controllers indicate by visual signaling to the supervisors which devices or conveyor lines they wish to have activated. Thus, a console monitors the status of the two giant parcel-post sorters and the conveyors and belts that feed a steady stream of packages to them. Another keeps tabs on the letter sorters. Another panel reports on the culling machines and facers.

Equally important to the smooth functioning of the daily mail handling procedures is the picture of traffic movement which the strategically located counters present in the control tower.

Positioned along the 17,000 feet of conveyors that keep the mail moving, the counters record numbers of processed sacks; outgoing sacks of mail; how many pieces of mail have been prepared for distribution to Providence, neighboring Rhode Island offices, and other national postal destinations; how much nonpreferential mail is in storage awaiting a slack period for processing; and the quality of trays of hand-processed mail, flats, and other special-handling pieces being worked.

LETTER SORTER—Each operator at the 11 letter sorters like this one in Project Turnkey can direct an average of 50 letters a minute to any of 300 destinations—an hourly total of 18,000 pieces of mail for each machine.

Using the numerical data presented on the counters, the control tower men can schedule the movement of mail. Truck and train schedules can be anticipated and met, and bottlenecks avoided before they occur. For example, if a train departure is delayed, the controller may notify the mail-sorting crew to continue processing mail for the carrier, after the normal scheduled deadline. Similarly, work situations at the start of new shifts can be evaluated and properly approached.

Another feature of the control tower is a public address system permitting the controller to speak to specific areas, including the basement, lobby, and adjacent lubritorium, where trucks are serviced. In addition to directions or announcements, music and significant audio broadcasts can be "piped" to the employees. **EE**

460-Kv Transmission Line Energized in Pennsylvania

CLAYSBURG, PA., SUBSTATION has joined the ranks of geographic locations signifying milestones in electrical industry research and development.

As Philo, Ohio, stands for progress in development of higher pressure steam for steam turbines, and Eastlake, Ohio, signifies the first use of a liquid as a cooling agent in a generator, Claysburg symbolizes the highest voltage in transmission equipment yet to be placed in commercial/experimental service by an electric utility in the United States.

At the Claysburg substation, the western terminus of the Pennsylvania Electric Company (Penelec) 13-mile extra-high-voltage (ehv) 460-kv transmission line, the General Electric Company has installed such outstanding electrical apparatus as the world's highest rated lightning arresters; highest rated power transformer, in terms of voltage, ever supplied an American utility; highest rated disconnect switch yet to be utilized by a utility, and the line itself is supported by several types of insulator assemblies of unprecedented design.

Electric power entering the Claysburg substation will come from the nearby 115-kv substation which handles the power on the existing 115-kv system paralleling the Penelec ehv line.

The electricity will first pass through 115-kv circuit breakers and carry to the two regulating transformers.

Low-voltage lightning arresters are then interposed in the buswork leading to the 3-phase autotransformer which is rated 1,425-kv BIL (basic impulse insulation level) and which will raise the voltage from 115,000 volts to the record 460,000 volts. The 50,000-kva ehv autotransformer, with its three 23-foot bushings (rising some 16 feet above the cover of the transformer), is of the forced-oil forced-air cooled type and weighs approximately 200 tons.

The world's highest rated lightning arrester installation was constructed at this point in the substation's circuit. The three Magnevalve station-class arresters, one for each line bundle, protect the power transformer and other apparatus on the line against lightning and/or switching surges to be experienced by the ehv line. The line will run through an area of high lightning activity.

A 460-kv 3-pole motor-operated air break disconnect switch will connect the buswork to the ehv transmission lines.

On one phase of the 3-phase line will be located a carrier-current coupling capacitor and wave trap for line measurement and protective relaying. The wave trap will permit the transmission or reception of frequency signals in the band

Courtesy Bethlehem Steel Company

PENELEC'S ehv transmission line crosses rugged terrain near Saxton, Pa., on heavy-duty steel suspension towers, detailed, fabricated, and galvanized at Bethlehem's Steel's Leetsdale, Pa., tower shop. Leg extensions are provided at corners of all towers to compensate for sidehill conditions.

Kaiser Aluminum Photo

ALUMINUM transmission conductor for Pennsylvania Electric Company's 460-kv prototype line is shown being produced by Kaiser Aluminum & Chemical Corporation at Newark, Ohio. The new 13-mile line, in south-central Pennsylvania, is achieving the highest voltages of any line serving an established transmission grid in America. Among the many other "firsts" for this project are: the use of the largest aluminum transmission conductor (2.32 inches in diameter); the utilization of a new type of electrical conductor which has hollow tubes in its core to increase the diameter; and testing with a new instrument to measure radio and television influence. The hollow core conductor and "square law" radio influence meter are Kaiser Aluminum developments. Kaiser Aluminum and Aluminum Company of America supplied all conductors for ehv transmission line.

from 90 to 200 kc from either terminus to simultaneously cut in or out the ehv line and the parallel 115-kv normal service line. In the initial stages of operation, protection will be provided by type *10* tone transfer trip equipment, and in the latter stages by types *17* and *15* carrier relaying and transfer-trip equipment.

At Saxton substation, the eastern terminus of Penelec's ehv line, General Electric has supplied such duplicates of the Claysburg substation equipment as lightning arresters, disconnect switches, line traps, and carrier equipment. All carry the same voltage rating as the western substation apparatus.

Across the rugged Western Pennsylvania terrain the 460-kv lines will be suspended from structures by insulator assemblies which are the longest yet to be utilized for transmission service, highest in insulating value, and the most complete in v-string construction and corona shielding.

General Electric provided 147 shielded insulator assemblies of unprecedented design for the project. Some 23 different varieties of insulator assemblies will be utilized in supporting the three twin bundle conductors at 33 tower structures, and the three massive single conductors at 11 structures.

The insulator assemblies themselves incorporate unusual mechanical requirements affording restraint against lateral movements while supporting the conductors flexibly under heavy ice and wind loads.

Ehv insulator assemblies are more than twice as strong as those used on the parallel 115-kv system line, and are slightly less than four times as long.

General Electric, in co-operation with Penelec, will make extensive lightning performance studies of the ehv line. An engineer will work from special instrument-equipped trailers atop the crest of Dunning Mountain above the Claysburg substation to measure and photograph lightning strokes as they hit the ehv line.

In addition, each of the lightning arresters at both the eastern and western terminus of the ehv line will be equipped with measuring instruments to provide test data on lightning arrestor discharges.

Extensive knowledge of the ehv transmission line's behavior under lightning bombardment will be of extreme value to the nation's utilities in reducing line outages due to lightning voltage surges. **EE**

Applications Invited For NSF Graduate Awards

Applications are being accepted for National Science Foundation (NSF) graduate fellowship awards for advanced study in the sciences.

Fellowships will be awarded in the mathematical, physical, medical, biological, and engineering sciences, including anthropology, psychology (excluding clinical psychology), and the following social sciences: geography, mathematical economics, econometrics, demography, information and communication theory, experimental and quantitative sociology and the history and philosophy of science. Also included are interdisciplinary fields which are comprised of overlapping fields among two or more sciences. The fields of research and study covered by these awards are limited to those which conform to accepted standards of scientific inquiry by fulfilling the requirements of the basic scientific method as to objectivity, verifiability, and generality.

To be eligible for graduate fellowships, applicants must be citizens or nationals of the United States and have demonstrated ability and special aptitude for advanced training in the sciences.

Fellows will be selected on the basis of ability as attested by letters of recommendation, academic records, and other appropriate evidence of scientific competence. Applicants for graduate fellowships are required to take the Graduate Record Examination. Applicants' qualifications will be evaluated by panels of scientists appointed by the National Academy of Sciences–National Research Council. Final selection of Fellows will be made by the NSF.

Stipends for NSF graduate fellowships vary with the academic status of the Fellows.

Application material for the National

Science Foundation Graduate Fellowship program may be obtained from the Fellowship Office, National Academy of Sciences–National Research Council, 2101 Constitution Ave., N.W., Washington 25, D.C. The closing date for the receipt of applications is January 6, 1961. Final selection of Fellows will be announced March 15, 1961. **EE**

Digiflex Machine To Retrain Persons Displaced by Automation

The invention of an automatic training machine which utilizes automation techniques to retrain people who themselves are being displaced by automation, was announced recently by USI Robodyne, a division of U. S. Industries, Inc.

Called Digiflex, the new equipment takes advantage of man's conditioned reflexes to speed the learning of manual skills. The U. S. Post Office Department has placed an initial order for 55 Digiflex machines at a cost of $115,000. The machines will be used to retrain postal clerks whose jobs have been affected by new automatic letter-sorting equipment in post offices.

Invented by E. F. Shelley, president of USI Robodyne, and John Goodell, director of engineering, the Digiflex trainer simulates the keyboards required to operate office and industrial automation equipment. It makes use of a simple human reaction: when a person's finger is pushed up, reflex action will automatically cause him to try to push his finger down again. By re-enforcing this instinctive reaction, Digiflex drastically reduces the length and difficulty of the learning period.

The first commercial application of Digiflex was designed to meet the specific training needs of the Post Office Department, where operators of new automated mail-sorting equipment must channel letters to the appropriate sorting bins.

Geared to this type of teaching need, Digiflex teaching equipment consists of three principal elements: (1) an instructor's station; (2) a student's station; (3) a special strip-film projector and related magnetic tape sound system.

One instructor's station can be linked electronically with as many as 20 student's stations. The instructor's station and the student's station bear a general resemblance to office desks, with small sections housing the complicated electronic equipment. The instructor's station contains a console panel incorporating all the controls necessary to govern operations of the teaching facilities.

When the projector flashes an address on a screen, an electronic impulse notes the appropriate code number, simultaneously raises on each of the 10-finger student's station keyboards the proper keys, and produces the code number audibly.

When the keys are raised on each student keyboard, reflex action causes the fingers to depress those keys.

In a very short time, the proper finger response is automatically and permanently established for the student. Further time is saved because the Digiflex bypasses the usual process of memorizing. In addition, it eliminates early errors and obviates the need to un-learn errors acquired in the early learning process under older methods.

Lights on the student's station and on a panel at the instructor's station immediately indicate whether each student's finger action was correct or incorrect. **EE**

Courtesy USI Robodyne

DIGIFLEX automatic training machine, which retrains persons displaced by automation, is shown in operation. Manufactured by USI Robodyne, a division of U. S. Industries, Inc., the machine consists of an instructor's station (left) and a student's station (right) as well as a projection screen and an integrated sound system. Digiflex utilizes automation techniques and human muscular reflex action for faster training of personnel. U. S. Post Office Department has already placed initial order for 55 Digiflex machines for retraining postal clerks whose jobs have been affected by new automatic letter-sorting equipment.

Future Meetings of Other Societies

American Nuclear Society, Annual Winter Meeting, Dec. 12-14, Mark Hopkins and Fairmont Hotels, San Francisco, Calif. Dr. E. Zebroski, General Electric Co., P. O. Box 254, San Jose, Calif.

Industrial Building Exposition and Congress, Dec. 12-15, New York Coliseum, Clapp & Poliak, Inc., 341 Madison Ave., New York 17, N.Y.

Atomic Industry Exhibition, Dec. 12-15, California Masonic Memorial Temple, San Francisco, Calif. D. J. Scherer, Atomic Industrial Forum, 3 E. 54th St., New York 22, N.Y.

Atomic Industrial Forum, Annual Conference, Dec. 14-16, Fairmont Hotel, San Francisco, Calif. Atomic Industrial Forum, 3 E. 54th St., New York 22, N.Y.

Heat Exchange Institute Meeting, Jan. 12-14, Seaview Country Club, Absecon, N.J. National Electrical Manufacturers Association, 155 E. 44th St., New York 17, N.Y.

American Astronautical Society, 7th Annual Meeting, Jan. 16-18. Sheraton-Dallas Hotel, Dallas, Texas. AAS, Box 14-1, Grand Prairie, Texas.

ISA Winter Instrument-Automation Conference & Exhibit, Jan. 17-19, Sheraton-Jefferson Hotel and Kiel Auditorium, St. Louis, Mo. Wm. H. Kushnick, Instrument Society of America, 313 Sixth Ave., Pittsburgh 22, Pa.

AIME, 3rd Mechanical Working Conference "Bar and Shaped Products," Jan. 18, Penn-Sheraton Hotel, Pittsburgh, Pa., American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 29 W. 39th St., New York 18, N.Y.

Industrial Heating Equipment Association, Inc., Jan. 23-24, Dearborn Inn, Dearborn, Mich., Air-Conditioning and Refrigeration Institute, 1346 Connecticut Ave., N.W., Washington 6, D.C.

Gaillard Seminar on Industrial Standardization, Jan. 23-27, Engineering Societies Building, 33 W. 39th St., New York 18, N.Y. Dr. J. Gaillard, 135 Old Palisade Rd., Fort Lee, N.J.

12th Annual Plant Maintenance & Engineering Show, Jan. 23-26, International Amphitheatre and Palmer House, Chicago, Ill. Clapp & Poliak, Inc., 341 Madison Ave., New York 17, N.Y.

SPE, 17th Annual Technical Conference, Jan. 24-27, Shoreham Hotel, Washington, D. C. R. D. Forger, Society of Plastics Engineers, Inc., 65 Prospect St., Stamford, Conn.

ASTM, Committee Week, Jan. 30-Feb. 3, Netherland-Hilton Hotel, Cincinnati, Ohio. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

8th Cleveland Electronics Conference, Jan. 31-Feb. 2, Engineering Center, Lapine Enterprises, Cleveland, Ohio.

Overseas

10th Electrical Engineers Exhibition, Mar. 21-25, Earls Court, London. Electrical Engineers (ASEE) Exhibition Ltd., 6 Museum House, 25 Museum St., London, W. C. 1, England.

"Phantom" Broad-Band Communication System Is Tested

THE ordinary background static heard when tuning in a radio program might someday conceal the presence of a military command being transmitted over a new broad-band communication system being developed and field tested by the General Electric Company's heavy military electronics department, Syracuse, N.Y.

Signals transmitted by this new military communications system will be as difficult to detect as "a needle in a haystack," according to Dr. J. P. Costas, General Electric consulting engineer, co-inventor of this new system with L. C. Widman, General Electric military electronics engineer.

Known as "Phantom," this broad-band communication system receives and transmits intelligent noise or static. It represents a new approach, different from the conventional narrow-band military communications technique in which each transmitter and receiver is allocated a specific narrow bandwidth to avoid interference and to crowd as many channels as possible into the electromagnetic spectrum.

In broad-band communications, Dr. Costas explained, the transmission bandwidth is many times larger than the intelligence bandwidth, or signal being relayed. For military communications, he added, broad-band techniques provide three types of security: security against jamming, because of the tremendous amounts of power required to interfere with the transmitted signal; transmission security, since the average power is spread over a wide bandwidth making the signal extremely difficult to detect; and message security, in that even if the signal is detected, it can be made very difficult for an authorized listener to understand what is being transmitted.

The "Phantom" communication system being developed by General Electric military electronic engineers overcomes the complexities associated with the known theory of broad-band communications so as to make it suitable for general-purpose military field use.

This new broad-band communication system uses a special form of double sideband transmission, resulting in transmission bandwidths that are much greater than those found in conventional practice, Dr. Costas disclosed. The prototype Phantom equipment is designed for use in long-haul high-frequency circuits where multipath conditions are encountered; however, it can be operated at frequencies much lower or higher than high frequency (3,000 to 30,000 kc) without any major design changes. Its operation is not restricted to any particular frequency.

Since the system's average power is spread over such a large bandwidth, conventional narrow-band circuits operating within the Phantom channel are unaware of its presence. In normal operation, the Phantom signal appears as random noise, or ordinary static, to conventional receiving equipment.

The data rate of the system is purposely kept low in relation to transmission bandwidth. This provides excellent jamming immunity and allows Phantom to be operated in heavily congested portions of the r-f spectrum. The system can tolerate the interference caused by other signals, and at the same time these other signals provide "cover," which enhances the transmission security of Phantom.

In order to receive the Phantom transmissions, an authorized receiving station must not only have the proper equipment, but also knowledge of the operating frequency and the specific signaling waveform being used, Dr. Costas stated. The present Phantom equipment has many hundreds of thousands of signaling waveform selections available which can be changed as often as necessary. Two Phantom systems operating in the same frequency band, but using different waveform selections, will appear essentially as random noise to one another. Conventional radio transmissions falling in the Phantom channel also appear as random noise to the system.

The Phantom communication system is much like a fine combination lock in the sense that detailed knowledge of the construction of the lock is of little or no help to the unauthorized, Dr. Costas added. It is designed so that it can still perform its military communications function even though the aggressor has access to its operating frequencies and complete knowledge of how it operates.

During recent field tests of the Phantom communication system, high-frequency signals were beamed successfully more than 2,000 miles from a transmitting site in the Southwest to special receiving equipment installed at the General Electric's Court Street plant in Syracuse. The results of these field tests conclusively prove the feasibility of this new broad-band communication system, especially for point-to-point communication in heavily congested portions of the r-f spectrum such as would be experienced during any military emergency, it was stated.

In fact, General Electric engineers working at the receiving site during the field tests with conventional equipment, even though they knew what to look for, were unable to locate, with any certainty, the signal being received by the Phantom equipment nearby. Many different frequencies in the high-frequency band were used during the tests.

High frequency was selected for the field tests because of the severe multipath and interference conditions normally encountered in this frequency range. Besides point-to-point communications, Dr. Costas foresees application of the system in aircraft and satellite communication systems.

EE

FINAL adjustments are made on the 100-foot-high television-like antenna (*left*) erected at the General Electric Company's heavy military electronics department, Syracuse, N. Y., for use in receiving signals during the recent field tests of the Phantom broad-band communication system. The 3-tier antenna is designed to receive signals at various frequencies. Right: Phantom I receiver is put through final verification tests. The equipment shown contains much auxiliary equipment which would not be necessary in normal operation. Although no attempt has been made to keep the present equipment small, it lends itself easily to transistorization and miniaturized packaging for mobile and fixed installations.

NEAR System To Alert Public

The first public demonstration of the National Emergency Alarm Repeater (NEAR) was conducted on the Consumers Power Company system in Charlotte, Mich., on October 11, 1960, by the Office of Civil and Defense Mobilization (OCDM). The NEAR system is a means of alerting the public in case of emergencies such as enemy attack or local disasters. This is accomplished by superimposing a 240-cycle signal on the electric power system which actuates a receiver giving an alarm at any desired location in a home, factory, office building, in fact any available 120-volt outlet. This demonstration was witnessed by about 350 persons including government officials, representatives of the press, radio, and television, and executives of the electric power industry.

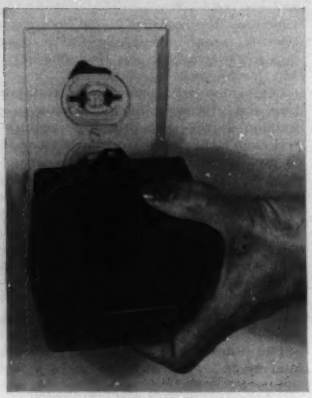
Principal speakers were L. A. Hoegh, director of OCDM; Brigadier General W. H. Duplantis USMC (Ret) and L. E. Berry of OCDM; and J. H. Campbell, President of Consumers Power Company. They described basic principles, test experience, and significance of the NEAR system in view of the constant threat of nuclear war.

The high point of the demonstration came when Mr. Hoegh pressed the alarm button in Charlotte before the assembled guests. This actuated a NEAR signal generator located on the Consumers Power Company system in Battle Creek, Mich., which in turn triggered a repeater signal generator located near Grand Rapids, Mich., about 60 miles from Battle Creek. After a 1-minute delay, receivers plugged into 120-volt outlets in the auditorium began buzzing in response to the signal being carried by the power system.

Approximately 1,500 NEAR receivers located in homes, offices, factories, and business places within the city of Charlotte, a city of about 8,000 population, were simultaneously set in operation. Upon receipt of the signal, Charlotte residents released 3-foot-diameter weather balloons, anchored to float 150 feet over the rooftops to demonstrate visually that the test was successful.

About 500 additional receivers were scattered throughout Michigan's lower peninsula in the areas served by Consumers Power Company. The Michigan control point for the OCDM National Warning System (NAWAS) was moved from its normal location at East Lansing to Charlotte for purposes of this demonstration. State police posts scattered throughout the state indicated whether the signal was received successfully via the NAWAS telephone network. The Battle Creek and Grand Rapids signal generators transmitted an effective alarm as far as the Straits of Mackinac, about 280 miles distant. The total area coverage amounted to about 14,000 square miles with a population of over a million persons.

Mr. Hoegh termed the test a success and pointed out that if the NEAR system is put into widespread use, it will be the greatest warning system of any country in the world. OCDM considers the system has been proven technically sound and no adverse effects on normal power service have been observed. It is estimated that for complete nationwide coverage, between 400 and 600 signal generators would have to be installed at strategic locations at an estimated total cost of about $50 million.



Office of Civil and Defense Mobilization Photograph

THIS National Emergency Alarm Repeater (NEAR) can link every American home, school, and business wired for electricity with the OCDM national warning system. Plugged into an electric outlet, the device can be activated by a special signal transmitted through the regular community power system. When activated, the alarm emits a loud, distinctive buzzing that warns residents to turn on a radio for emergency information. The device, manufactured by AC Spark Plug Division of General Motors, can be triggered in a matter of seconds after warning is received.

It was originally conceived that civil defense alarms could best be transmitted via electric power systems because they reach over 96% of the nation's population, significantly more than any other public service. Principles of the NEAR system were developed by Midwest Research Institute of Kansas City for OCDM. Planning for large-scale tests to perfect and establish the practicality of the NEAR system was commenced in late 1956 under a co-operative arrangement between OCDM, Consumers Power Company, and the Midwest Research Institute, with Commonwealth Associates, Inc., serving as consultants to Consumers Power Company.

Actual tests were begun in February 1958. These tests were conducted with considerable caution because most of them were highly experimental and on circuits carrying electric service to Consumers' customers. An important problem was to perfect a signal which could be imposed on the electric system without impairing service. Also, the signal had to be of a type which could not be triggered by natural occurrences on the power system.

The signal generators which actuate the NEAR system are basically iron core reactors delta connected between phases. While signaling, the core is saturated by passing d-c current through a secondary winding. The Battle Creek and Grand Rapids signal generators were manufactured by the General Electric Company.

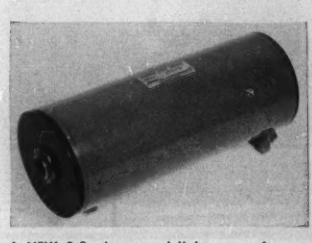
The signal is received by a small alarm device which plugs into any standard 120-volt a-c outlet. This instrument is approximately 3 by 3 by 2 inches and may be secured to the wall outlet to prevent its being knocked out or removed. When a 240-cycle signal of 10 seconds or more is received over the power line, the alarm will sound for about 50 seconds and then shut itself off. If the signal is repeated or continued on the power line, the alarm will sound again after a 10-second delay. About 2,000 of these receivers have been manufactured by the A-C Spark Plug Division of General Motors Company for test purposes. It is estimated these alarm devices could be mass produced for about $5 to $10 each and would use about 50¢ worth of electricity a year.

Specially coded receivers may be used when the device becomes operational, which will permit alarming key personnel only, rather than the general area. Also, functions such as turning on sirens, street lights, or similar devices may possibly be performed by this system. Joint use of the NEAR system by utilities to perform widespread control functions such as off-peak water heater switching is a possibility. **EE**

Light Source With 0.3-Microsecond Burst

A burst of light as fast as 0.3 microsecond is produced by a new light source for photographic motion studies designed by the Avco Research and Advanced Development Division in Wilmington, Mass. The high-intensity spark light was originally developed to study hypervelocity flights of advanced-design model nose cones for the Air Force Titan and Minuteman ICBMs on the Avco Ballistics Range.

The light source may be incorporated into instrumented shadowgraph and schlieren systems. In a basic shadowgraph system for laboratory work, the unit may be used alone in a manner similar to the open-shutter flash-bulb technique.



A NEW 0.3-microsecond light source for motion studies to enable photographic "freezing" has been designed by Avco Research and Advanced Development Division in Wilmington, Mass. The capacitor-discharge high-intensity burst of light, illuminating models, gases, or chemicals reacting at high speeds, may be incorporated into instrumented shadowgraph or schlieren systems.

Four models are available to provide spark light duration from 0.3 to 1 microsecond. Size of the point light source varies from 0.015- to 0.060-inch diameter, depending on the energy level which may range from 2 to 20 joules. The spark pulse may be sychronized with a Kerr Cell shutter. A voltage pulse is also produced to initiate other measuring devices.

The light source is a cylindrical package, called type *LS-020*, 12½ inches long by 5 inches in diameter, with a coaxial discharge path. The outer case serves as an r-f shield and once the unit is positioned, the component package may be removed, adjusted, and returned to the case without disturbing the optical alignment. The unit operates by discharging a coaxial capacitor in an air gap. **EE**

Data-Phone Network Installed by Insurance Group

A data-communications network is being installed by Hardware Mutuals–Sentry Life to facilitate greatly expanded growth which is expected to double the gross business of the mutual property-casualty insurance group within the next decade, J. P. Jacobs, president, announced recently.

Utilizing the Bell Telephone System's Data-Phone method of transmission over the regular telephone network, Hardware Mutuals–Sentry Life are linking their headquarters in Stevens Point, Wis., with 32 of their branch offices throughout the country.

Business machines talking to each other over the telephone will help to cut the time normally required by the industry to provide complete customer service from "up to two weeks to less than two days," Mr. Jacobs said.

"Our new arrangements for transmitting and processing insurance data in a fraction of the time previously required will enable Hardware Mutuals–Sentry Life to greatly speed policyholder service, reduce operation costs by more than $1,000,000 annually and effect an important increase in investment income," Mr. Jacobs said.

The new data-processing center will produce complete daily operating statements for Hardware Mutual Casualty Company, Hardware Dealers Mutual Fire Insurance Company, and Sentry Life Insurance Company in 17 minutes.

The insurance companies will utilize a total of 36 Data-Phone sets, making this the largest Data-Phone installation in the nation serving business.

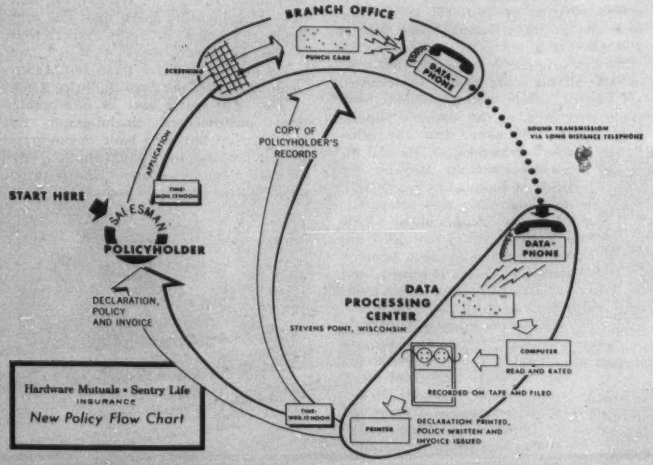
Four Data-Phone sets will be installed at the companies' Stevens Point data-processing center and 32 Data-Phone installations will link the companies' major offices. A total of 13 installations have been made to date, including two at Stevens Point. The remainder will be in service by the end of the year.

R. H. Deck, Hardware Mutuals vice-president in charge of data processing, explained that the Bell System Data-Phone service and IBM equipment will send complete details on new auto insurance applications, premium payments, and policy changes into the center over regular telephone lines at speeds equivalent to more than 100 words per minute.

Policy records formerly stored in voluminous "live" files in district and home offices will be filed instead on magnetic tape for easy access for premium billing, policy renewals, or customer service inquiries. The electronic computer, one of the first IBM *7070* transistor installations in private industry, will scan every private passenger auto policyholder's record every 24 hours. It will record address changes, new car purchases, premiums paid, and claims payments. Up-to-date information cards for customer service files will be Data-Phoned to branch offices daily. Rates will be verified and new auto insurance policies issued overnight.

New insurance policies will be in the mail within 48 hours from the time car owners sign applications, Mr. Deck said. "Annoyances due to slow manual and mail handling of policyholders' premium checks will be virtually eliminated."

"The flexibility and versatility of Data-Phone will promote economy by enabling us to pay for phone lines only when we use them," Mr. Deck said. The in-use charge for Data-Phone, which converts business machine data into tones suitable for transmission over the regular telephone network, is the same as for normal voice conversations. **EE**



INSURANCE POLICIES from Hardware Mutuals–Sentry Life are now in the mail to customers within 48 hours from the time salesmen take applications. Policy information is sent from any of 32 branch offices from Boston to Santa Barbara by means of the Bell System's Data-Phone which converts punched card codes into tones and transmits them over regular long distance telephone lines. Data-Phone sets and business machines at the companies' headquarters in Stevens Point, Wis., reconvert the tones back to duplicate punched cards. Policy information is read, rated, and recorded on tape by means of an IBM computer. Then, the declaration is printed, the policy written, and an invoice issued.

Scientists Measure Radio Waves from Saturn

University of Michigan (U-M) scientists have measured radio waves from the planet Saturn and from a planetary nebula —a remote and gas-surrounded dying star, the University's head of radio astronomy reported recently.

U-M Prof. F. T. Haddock reported these first clear and unambiguous detections and measurements of Saturn and a planetary nebula to the 13th General Assembly of the International Scientific Radio Union.

The findings are basic contributions to scientific knowledge. They could also help save money in future planetary exploration and possibly lead to modification of theories of planetary nebulae.

The measurements were made with the U-M's high-precision 85-foot radio telescope through the use of a new and highly-sensitive ruby maser amplifier. This amplifier was developed by the University's Willow Run Laboratories in an application of its earlier discovery, in 1957, of maser action in ruby.

The measurements were made by J. J. Cook and L. G. Cross, of Willow Run Laboratories, and A. H. Barrett and W. E. Howard, III, of the Radio Astronomy Observatory. Mr. Cook and Mr. Cross also designed, built, and installed the ruby maser amplifier.

Saturn's atmospheric temperature was found to be 100 degrees Kelvin (—283 F), about the temperature expected on the basis of optical studies. The naturally generated radio waves are emitted from various depths in the planet's atmosphere.

The measurement may make possible study of the temperature and density of the rings of Saturn and of the distribution of gases in Saturn's atmosphere. Precise measurements at a number of frequencies are needed for this, Prof. Haddock pointed out. The U-M findings are accurate within 10%.

Planetary nebulae are stars, like our sun, which, however, are in the last stages of their lives. Each consists of a small hot central star surrounded by a very thin "high vacuum" gas cloud some millions of millions of miles in diameter. The central star in each is atomically burning itself up; its mass turning into energy which excites the gas particles into giving off radio waves.

Measurement of a planetary nebula—in this case one 3,000 light years away designated NGC (New Galactic Catalog) 6543—is significant because these sources are small and very distant. Their radio emission has been looked for for some time but had not been definitely measured before.

Such measurements can help determine electron densities in the gas envelope, Prof. Haddock said.

"Combined with optical and additional radio measurements, it will be possible to shed light on the evolutionary processes of stars, the physical characteristics of planetary nebulae, and perhaps detect both the existence of magnetic fields in nebulae and cosmic ray electrons surrounding these nebulae," he pointed out.

Together, optical and radio observations can thus help astronomers determine how stars age and die.

Prof. Haddock said astronomical observations of the planets will be basic to their later exploration by space probe instrumentation and by man, and could thus save millions of dollars in space exploration planning.

For instance, radio studies of Jupiter revealed intense radiation belts that could damage electronic equipment and photographic recording film on a space probe sent there. And the surface temperature of Venus has been found by radio astronomers to be much hotter than expected—around 580 F. Only radio astronomy could discover this because the planet is enshrouded in a permanent cloud cover.

The measurement of Saturn and NGC 6543 are due largely to the ruby maser amplifier.

The maser's value to radio astronomy lies in its relative absence of the self-produced static inherent in standard radio receivers. This static can drown out weak incoming signals in conventional radio amplifiers. **EE**

"Magnyl"—Flexible Magnetic Tape

A new concept of the application of permanent magnets to a greatly expanded variety of products is realized in **Magnyl**, a flexible vinyl tape into which finely divided magnetized particles are uniformly distributed.

One side of the tape exerts strong magnetic attraction over its entire surface. The other side is practically nonmagnetic.

The nonmagnetic side can be molded, embossed, hot-stamped, printed, silk-screened or laminated with printed or unprinted foils, films, or papers. It may be cut with a scissors or die-cut in mass production.

Applied Magnetics Corp., Leeds, Mass., who will process and distribute Magnyl, see in this new material a definite break in both design and cost barriers which have limited the use of magnets in products for consumer and industry.

The product design barrier is broken because there are no limitations requiring that the product conform to the magnet. With Magnyl, the magnet itself can conform to the product.

The cost barrier is broken. For many applications, conventional magnets cannot be used because of cost. With Magnyl, both because of its lower basic cost and its ease in handling, new vistas of application are opened.

Applied Magnetics will furnish Magnyl in standard bulk rolls, dark brown in color, in widths from 5/16 to 2 inches and in thicknesses from 1/16 to 1/4 inch. Special widths, thicknesses, and colors will be available to order. The company will also print, mold, die-cut, and laminate to order. The material can also be extruded to order for special shapes.

Many and varied are the consumer and industrial uses already developed for Magnyl.

In industry, uses have been developed for production control boards, assignment boards, gaskets, a masking material for production finishing. It can stand the heat of baking ovens, be stripped off and reused for another production run. It is thus said to be more economical and more easily applied than pressure-sensitive masking tapes. **EE**

Model of Space Radiator Demonstrated

A working model of a unique heat radiator for earth satellite and interplanetary space vehicles was demonstrated publicly for the first time recently by Rocketdyne, a division of North American Aviation, Inc.

Designed to overcome the problem of getting rid of waste heat which will be generated in nuclear-powered space vehicles, the device is known as a moving belt radiator.

In addition to providing a practical means for removing heat from a space vehicle, the moving belt radiator is lighter in weight than previous radiator designs and can withstand bombardment and penetration by meteoroids encountered in space.

Conceived and designed by Rocketdyne's Nuclionics subdivision, the moving belt radiator design is an outgrowth of more than 4 years of research studies in nuclear power problems for interplanetary space vehicles.

"The moving belt radiator is a major advancement in interplanetary space vehicle design," Dr. R. B. Dillaway, manager of Nuclionics, said. "It is lighter by two thirds than so-called conventional tube and fin radiators which have been proposed. It provides for the control of the amount of radiation so that space power systems can be run at different levels as required."

The moving belt radiator works as follows:

Twin belts extend from the waste heat rejection core, one on each side. They move continually, picking up the heat from the outer surface of the core and radiating it from the surfaces of the belts as they rotate in space.

At launch, the belt would be wrapped around the generating assembly and enclosed in a disposable aerodynamic shield. After the vehicle has reached its orbital flight path, the shield would be jettisoned. The belt then would unfold automatically and the radiator carriage would begin to revolve about the power conversion capsule at a predetermined speed.

The whirling speed of the belt assembly can be preset to maintain a constant temperature in the radiation system under any power level of operation desired.

Because of its relatively light weight as compared to tube and fin type radiators, advantages gained by using the moving belt radiator increase as the power of the space vehicle increases. However, it can also be used effectively for a relatively low powered unit such as SNAP 8 (Systems for Nuclear Auxiliary Power).

A specific design study of a 300-kw nuclear-powered vehicle showed that the moving belt radiator would be approximately 80 feet long and would weigh about 800 pounds as compared to 1,800 pounds for a tube and fin radiator for the same vehicle.

Preliminary tests of the present model now are being made in a special vacuum chamber in which space environment can be simulated up to 40 miles. Future tests will be made in vacuum chambers in which space conditions can be simulated up to several hundred miles. **EE**

ARTIST'S DRAWING of moving belt radiator for earth satellites and interplanetary space vehicles developed by Rocketdyne, a division of North American Aviation, Inc. Radiator is much lighter than proposed tube and fin type and will continue to operate even if punctured by meteoroids in space. Model of radiator is now undergoing tests in vacuum chamber which simulates space environment.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, *Electrical Engineering* reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, doube-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Energy-Conversion Research

October 7, 1960

To the Editor:

The paper by S. W. Herwald in the September 1960 issue (pp. 741-43), "The Role of Industry in Energy-Conversion Research," is a rather enlightening discussion of this engrossing problem and challenge to our technology in some aspects. Mr. Herwald indicates some difficulty in discriminating between basic energy sources and energy-conversion devices as a principal concern of industry, both concerns being so inextricably interlocked.

Perhaps I might introduce a few ideas on the subject. Energy sources are fairly well defined in nature, and can be categorized as stored energies (e.g., fossil fuel, volcanic heat, nuclear) and transitory energies (e.g., solar radiation, wind, wave, hydro, radioactive decay). The stored energies are being depleted at an unprecedented rate, as Mr. Herwald points out in the interesting optimistic and pessimistic comparisons. Other authors* have indicated that the present rate of consumption of stored energies is about 470,000 times faster than nature stored them. Yet, this is not a matter of too grave concern, apparently, when it is realized that relatively little research or use is made of the transitory energy forms, which are not so simply or reliably converted and regulated for use in "frequency-fussy" power systems and utilization equipment. This writer ventures to predict that the fossil-fuel-fired power plant will be obsolescent a few centuries before the last fossilized Btu is mined.

Certainly the fuels that are used depend strictly upon comparative engineering economics: witness the slow development of utilization of nuclear energy in commercial power systems today. It appears that there yet might be a greater development of the transitory energy sources before the fossilized and nuclear sources are depleted. It should be noted that the development of transitory energy defers the consumption of stored fuels, which are vitally needed for industrial uses other than power. Also, it should be considered that as an energy-conversion system, the relative efficiency of a transitory energy system may be higher than that of a stored energy system. For example, compare the energy-conversion system for the generation of electric power from a coal-fired steam plant vs. a hydro plant (accompanying table).

It is seen that as an energy system, from the standpoint of efficiency only, a hydro plant (transitory energy) is truly remarkable, so long as the sun regenerates the fuel supply. But it is often an economic pitfall to accept efficiency purely as a comparison between two decimals, and the higher the better, without measuring the influence of other factors. Thus, it is believed to be technically sounder to consider the over-all energy system when the principal concern is the future of the main (stored) energy sources; and, step efficiency when a particular fuel is being utilized. As efficient as the fuel cell itself promises to be, what will be the efficiency of the fuel system to supply it? In this sense, also, a great deal more effort could be expended by industry to develop more widely and efficiently the transitory energy systems, which are at least regenerative and, in the long run, may be the only source of energy left on earth. In the energy system sense, too, we should be more concerned with the efficiency of end-use. For example, we know that our modern over-powered automobiles for private transportation are part of an extremely poor efficiency energy system, but that is not of real concern either in the wasting away of our energy sources. Perhaps the automotive industry should be more concerned than it appears to be with specific fuel consumption. But I guess this will have to wait for quite awhile before our prodigal society becomes concerned or astute enough really to do something about the rapid depletion of our energy reserves.

Very truly yours,
HENRY J. ANTOSZ (M '56)

(Department of the Navy, Bureau of Yards and Docks, Washington, D.C.)

* Ayers & Scarlott, "Energy Sources—Wealth of the World"

Comparison of Energy-Conversion Systems
(Electric Power Generation)

Step	Coal-Fired Plant		Hydro Plant	
	Step. Eff. %	Over-all Eff. %	Step. Eff. %	Over-all Eff. %
1. Production of fuel	96	96	—	—
2. Transportation of fuel	97	93	—	—
3. Conversion of energy	30*	28	(Turbine, 90 Generator, 95)	85.5
4. Transmission of energy	80	22.4	80	68.4

* As an average, about 22 may be more discrete

Role of Technical Supervisor

September 26, 1960

Dear Dr. Green:

I have just had an opportunity to read your excellent article on "The Role of Technical Supervisor" which appeared in the September 1960 issue of *Electrical Engineering* (pp. 715-18).

For whatever my opinion is worth, I think this article covers all important elements of the subject in both a complete and easily understood fashion. Moreover, I fully concur with your recommendations, based on my own experience and observations. I think the principles enunciated in your article have wide application outside the strictly research and development field.

My personal feeling is that *Electrical Engineering* should print more articles of this type, although my opinion may be in the minority.

Sincerely yours,
C. T. PEARCE

(Manager, Atlantic Region Engineering & Service, Westinghouse Electric Corporation)

NEW BOOKS

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ALTERNATING-CURRENT CIRCUITS. By R. M. Kerchner and G. F. Corcoran. Fourth edition. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N.Y., 1960. 602 pages, 6 by 9¼ inches, bound. $8.75. The numerous changes and additions in this edition of a standard college text are designed to make introduction of the subject more understandable to students. An introductory chapter on network concepts has been added, and material on complex frequency and poles and zeros included as preparation for succeeding advanced courses. The book adopts the term "phasor" for a time-varying quantity which is handled by vector methods, and the change from vector to phasor diagram is made in chapter 4. Knowledge of differentiation and integration is required.

ALTERNATING-CURRENT CIRCUITS. By K. Y. Tang. Third edition. International Textbook Company, Scranton, Pa., 1960. 612 pages, 6¼ by 9¼ inches, bound. No price given. The major changes in this edition of a standard text for use in an introductory course in electrical networks are toward a more general and unified approach. Instantaneous values and transient response are emphasized, although steady-state conditions are treated with sufficient thoroughness. The rationalized MKS system of units is used, and numerical examples and problems employ round figures to

stress exercise of problem-solving techniques as opposed to slide-rule manipulation.

ANALOGUE AND DIGITAL COMPUTERS. Edited by M. G. Say. Philosophical Library, Inc., 15 E. 40th St., New York 16, N. Y., 1960. 308 pages, 5¾ by 9 inches, bound. $15. This is a presentation of the basic material on the design and application of analog and digital computing systems for newcomers to the computer field, composed of chapters contributed by British specialists in the field.

ANALYSIS AND DESIGN OF FEEDBACK CONTROL SYSTEMS. By G. J. Thaler and R. G. Brown. Second edition. McGraw-Hill Book Company, Inc., 330 W. 42nd St., New York 36, N.Y., 1960. 648 pages, 6¼ by 9¼ inches bound. $14.50. This is the second edition of a senior college text, "Servomechanism Analysis." Extensive alterations, including the change of title, result from integration of material in both design and analytic aspects of feedback control theory. Chapters 1 to 7 constitute a basic course in feedback controls, and 8 to 9 discuss design principles and their application. The remaining chapters cover Mitrovic's method for analysis and synthesis, sampled-data servo systems, phase-plane analysis of nonlinear servos, describing functions, and relay servomechanisms. The up-dated appendices include the Nichols chart, and description of error detectors, servomotors, and compensating devices.

ATOMKRAFT. By Friedrich Münzinger. Springer-Verlag, West Berlin, Germany, 1960. 403 pages, 6½ by 9½ inches, bound. DM 42. This is an introduction to the problems involved in the construction of nuclear power plants intended for engineers, industrialists, and power economists. The first three sections deal with the theoretical fundamentals of nuclear energy, reactor technology including heat engines and economic aspects of nuclear plants as power producers. A new chapter in the revised edition covers nuclear propulsion for ships, airplanes, etc.

DICTIONARY OF AUTOMATIC CONTROL. By R. J. Bibbero. Reinhold Publishing Corporation, 430 Park Ave., New York 22, N. Y., 1960. 282 pages, 5¼ by 7¾ inches, bound. $6. A unique feature of this book is an index arranged under the five major subject divisions the book covers—control theory and basic concepts, computers and data processing, industrial machine and process control, aircraft and missile control and telemetering, and control components and design features—which assists in the location of a particular term, as in a thesaurus. In the main text the terms are dealt with alphabetically by means of a brief discussion rather than just a definition. Extensive cross-referencing permits discussion of related terms or concepts under one heading in a unified essay, rather than in alphabetically separated explanations. A chief engineer at Bulova Research Laboratories, consulting editor of the magazine *Automatic Control*, and member of AIEE, IRE and AAS, the author has spent 5 years collecting, editing, and interpolating the material.

DIGITAL COMPUTERS AND NUCLEAR REACTOR CALCULATIONS. By W. C. Sangren. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N.Y., 1960. 208 pages, 6 by 9¼ inches, bound. $8.50. A primary objective of this book is to present to the nuclear engineer or scientist an introduction to high-speed nuclear-reactor calculations. One small reactor calculation is discussed thoroughly and a number of representative types of calculations is considered briefly. The first four chapters deal with an introduction to reactor problems, digital computers, programming, and numerical analysis, and the last four with considerations involved in actual reactor calculations.

ELECTRICAL DESIGN DETAILS. By J. F. McPartland and W. J. Novak. McGraw-Hill Book Company, Inc., 330 W. 42nd St., New York 36, N.Y. 1960. 231 pages, 8½ by 11¼ inches, bound. $8.50. This book was developed as a quick and practical reference file of ideas for electrical design. The diagrammatic material, adapted from the magazine *Electrical Construction and Maintenance*, represents all phases of electrical distribution and circuitry in industrial plants, commercial buildings including airports, tunnels, bridges, streets, and highways, and residential elements including private houses, farms, hotels and trailer parks.

ELEMENTARY INTRODUCTION TO NUCLEAR REACTOR PHYSICS. By S. E. Liverhant. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N.Y., 1960. 447 pages, 6¼ by 9¼ inches, bound. $9.75. This textbook for undergraduates in physics and engineering is an elementary account of that branch of physics involved in the study and design of nuclear reactors. The first three chapters deal with fundamental aspects of nuclear physics directly related to the physics of nuclear reactors. The discussion then develops the concepts of the compound nucleus, neutron cross-sections, and their relationship, and examines the physical aspects of nuclear fission, the interaction of neutrons with matter in bulk, and thermal and fission neutrons. Neutron diffusion theory then is considered, and the nonstationary reactor described and explained. The concluding chapters deal with the detection, measurement, and safeguards against nuclear reactor radiations.

ELSEVIER'S DICTIONARY OF AMPLIFICATION, MODULATION, RECEPTION AND TRANSMISSION. IN SIX LANGUAGES. Edited by W. E. Clason. D. Van Nostrand Company, Inc., 120 Alexander St., Princeton, N.Y., 1960. 804 pages, 6 by 9 inches, bound. $25. The basic list contains 2924 numbered terms with their subject classifications and definitions in English, distinguishing between British and American usage, and their French, Spanish, German, Italian, and Dutch equivalents. Appendices list alphabetically in each of the latter five languages these terms which are keyed to the basic list. Telecommunications terms not specifically involved in the restricted subject field chosen are omitted.

HOW TO CHART DATA. By Phil Carroll. McGraw-Hill Book Company, Inc., 330 W. 42nd St., New York 36, N.Y., 1960. 260 pages, 6¼ by 9¼ inches, bound. $7.50. Here are discussed the type of data required in the solution of various management problems in areas of work measurement, plant scheduling, and control of costs, and the ways of presenting them in easy-to-analyze forms. Six different chart forms are dealt with in detail, their development shown in progressive illustrations, and the general conditions for their use pointed up.

INTERNATIONAL MISSILE AND SPACECRAFT GUIDE. By F. I. Ordway III and R. C. Wakeford. McGraw-Hill Book Company, Inc., 330 W. 42nd St., New York 36, N.Y., 1960. Various pagings, 9 by 11¼ inches, bound. $25. This is a handbook on specific missile systems, with emphasis on American missiles, due to greater availability of information in the place of publication. It analyzes individual missiles of each country and relates given systems to other similar systems and to a general class of military or research vehicles. Illustrated descriptions and available technical specifications, from unclassified sources of information only, are given for the major guided and unguided missiles. Facts only are given for existing types, but informed fancy is indulged in sections covering future evolution. A key feature is inclusion of missiles that never reached the manufacturing stage, providing little-known but useful information. Another feature is the "chronology of missile progress," with its extensive performance data tables, and "organization of missile authorities," arranged by nation and listing names and addresses of Government agencies, industrial firms, research organizations, universities, associations and the like, active in the missile field.

INTRODUCTION TO CONGESTION THEORY IN TELEPHONE SYSTEMS. By R. Syski. Oliver and Boyd, Edinburgh, England, 1960. 742 pages, 6½ by 10 inches bound. £5.5. The purpose of this book is to present the study of stochastic processes describing the passage of telephone traffic through a switching system, and to introduce to telephone engineers recent mathematical developments in the general congestion theory applicable to telephone traffic. Strong emphasis is placed on the variety of the mathematical methods employed for the solution of congestion problems. Considerable use is made of such recent developments in general congestion theory as queueing theory, Markov chains, and renewal processes.

Library Services

ENGINEERING Societies Library books, except bibliographies, handbooks, and other reference publications, may be borrowed by mail by AIEE members for a small handling charge. The Library also prepares bibliographies, maintains search and translation services, and can supply a photoprint or a microfilm copy of any item in its collection. Address inquiries to R. H. Phelps, Director, Engineering Societies Library, 29 W. 39 St., New York 18, N. Y.

MANAGEMENT OF NUCLEAR MATERIALS. Edited by R. F. Lumb. D. Van Nostrand Company, Inc., 120 Alexander St., Princeton, N.J., 1960. 516 pages, 6¼ by 9¼ inches, bound. $16.50. The purpose of this book is to accumulate in one place the basic philosophies and practices developed by the Atomic Energy Commission and its contractors for maintaining control over nuclear materials. It will be of interest to organizations having to control either nuclear materials or nonnuclear materials of somewhat similar, unique characteristics. Discussion is restricted to control of uranium and plutonium as exemplifying procedures for all nuclear materials. It also covers general background materials as well as detailed information conveyed by means of case histories. The complete chain of operations is described, from the procurement and processing of uranium ore, through refinement of uranium, separation of isotopes, fabrication of reactor fuel elements, and their use in reactors, and recovery and utilization of plutonium, as well as scrap and irradiated fuel recovery and the material control aspects of research and development activities.

NATIONAL ELECTRONICS CONFERENCE—PROCEEDINGS, Volume XV. Published by the National Electronics Conference, Inc., 228 North LaSalle St., Chicago 1, Ill., 1960. 1089 pages, 6¼ by 9¼ inches, bound. $10. This volume contains technical papers 1183 to 1290 as presented at the 25th National Electronics Conference, October 1959. The 24 topical groups into which the papers are organized include adaptive servomechanisms, parametric amplification, audio, communication systems, computers, electronic devices, automatic control, perception and recognition, low noise devices, information theory, engineering management, radar, antennas, and engineering writing and speech.

NEUTRON DETECTION. By W. D. Allen. Philosophical Library Inc., 15 E. 40th St., New York 16, N.Y., 1960. 260 pages, 5¾ by 8¾ inches, bound. $10. This is a book for those with some background knowledge of nuclear physics and particle detectors, who require a more detailed knowledge of the main methods of neutron detection. For the less experienced readers, Chapters 1 and 3 summarize the necessary elements of nuclear physics and particle detection. The author describes in detail those methods which he considers important, mentioning only in passing or in the bibliography many others. The neutron energy range above 20 mev is covered only in occasional illustration of extension of techniques established for neutrons of energy less than 20 mev. It covers material up to the end of 1957, with some bibliographical references up to the end of 1959.

PRECISION MEASUREMENT AND GAGING TECHNIQUES. By William Grohe. Chemical Publishing Company, Inc., 212 Fifth Ave., New York, N.Y., 1960. 222 pages, 5¾ by 8¾ inches, bound. $7.50. The primary purpose of this book is to acquaint the technical and engineering student with up-to-date instruments, methods, and techniques used in inspection and gaging. The author discusses screw, unified, and American National Taper threads from the standpoint of accuracy checks, and describes ramp and fixed gages,

precision gage blocks, and pneumatic gaging. Other topics covered include mechanical and electronic comparators, optical measuring instruments, measurements with light waves, evaluation of surface roughness, harness testing, torque wrenches, and the use of the slide rule.

PROGRESS IN DIELECTRICS, Volume 2. Edited by J. B. Birks. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y., 1960. 225 pages, 6¼ by 9¼ inches, bound. $9.50. The main theme of this volume is dielectric properties in weak electric fields. An introductory survey is given in a paper presenting the theory of dielectric polarization and absorption. Next, a detailed review and comparison of the dielectric properties of polymeric systems is presented, followed by a discussion of the present state of knowledge of the physico-chemical effects of radiation on high polymers. Then two papers discuss inorganic dielectric materials, one, the dielectric properties of glass, and the other, high-permittivity ceramics. The final paper reviews artificial dielectrics; arrays of conducting and nonconducting elements for use where conventional dielectrics are unsuitable.

THERMOELECTRICITY. Edited by P. H. Egli. John Wiley & Sons, Inc., 440 Fourth Ave., New York 36, N.Y., 1960. 407 pages, 6 by 9¼ inches, bound. $10. Much of the material in this book is from the 1958 Conference on Thermoelectricity sponsored by the U.S. Naval Research Laboratory. Section one is an introduction to and a broad survey of fundamental concepts. Section two deals with basic parameters, examining the physics of the properties which determine thermoelectric performance and discussing thermal conduction and electronic transport in terms applicable to thermoelectric materials. Section three studies the chemical and physical properties of materials at high temperatures. Section four discusses the measurement of material properties, emphasizing high temperatures, and examining the relative merits of static and transient methods of measuring thermal conductivity.

TECHNICAL LITERATURE

The following recently issued technical literature may be of interest to readers of *Electrical Engineering*. All inquiries should be addressed to the issuers.

BASIC HUMAN FACTORS FOR ENGINEERS. *The Task Analysis to the Human Engineering of Men and Machines.* P. A. Verdier, engineering psychologist, presents in this manual a practical method of task analysis to provide the average engineer with the first uniform approach to the exciting new field of human engineering. The method, explained in simple language, presents the basic facts of applied psychology in symbolized form. The reader will learn just what human factors are, how to flag them out, and how to utilize them in solving engineering problems. Designing equipment and systems for optimum human usage, organizing a human-engineering department, illustrations of task analysis, human-factors working forms, performance-test scoring and diagnosis, and personnel evalutation are some subjects treated in the book. Priced at $4 per copy, it is available from Exposition Press Inc., 386 Park Ave. South, New York 16, N.Y.

RESEARCH AS A SCIENCE—ZETETICS. Detailed proposals and basic outline for "zetetics" are presented in a new book by Prof. Tykociner of the University of Illinois, Department of Electrical Engineering. The author emphasizes that the science of research is not concerned with the nature or administrative organization for conducting research. His aim is to establish a basis for the collection and systematization of all information about research itself, including the creative process. That is the knowledge, Prof. Tyciner says, that leads to discoveries, inventions, and the solution of human problems. Copies of the book may be obtained from the Office of Publications, 114 Civil Engineering Hall, University of Illinois, Urbana, for $2 each.

PRINCIPLES OF ENGINEERING ECONOMY. Written by Profs. E. L. Grant and W. G. Ireson of Stanford University, this revised fourth edition analyzes the economic aspects of engineering decision making. It gives basic principles for making of practical decisions such as acquisition and retirement of capital goods, the choice between alternative methods of financing, and income tax considerations of investment proposals. Two fundamental points are stressed: it is only prospective differences between alternatives that are relevant; and a proposed investment should provide a financial return commensurate with the returns obtainable from other opportunities for investment of limited funds. Special attention is paid to capital rationing, analysis involving mathematics of compound interest, operations research concepts, etc. 574 pages, 98 illustrations, priced at $8, it is available from the Ronald Press Company, 15 E. 26th St., New York 10, N.Y.

AMERICAN STANDARDS. *American Standard Method for Specifying the Characteristics of Auxiliary Equipment for Shock and Vibration Measurements, S2.4-1960.* This publication will enable users of said equipment to request information, utilizing standard terminology, from the manufacturer. Special emphasis has been given to preamplifiers; linear and logarithmic amplifiers; frequency selective equipment, which includes band-pass filter, wave analyzers, octave-band analyzers, integrating circuits, and differentiating circuits; and carrier systems. Price 80¢. *American Standard Requirements for Varnished Cloth Insulated Cables, C8.13-1960* applies to all sizes and classes of underground, aerial, and indoor power cables operating at voltages not exceeding 10,000 volts for nonshielded multiple conductor cables and 28,000 volts for other types and maximum conductor temperatures ranging from 70 to 85 degrees calcius which are insulated with varnished cloth and used for the transmission and distribution of electrical energy. Price $2 per copy. *IEC Recommendation for the Dimensions and Output Ratings of Electric Motors, Part 2: Dimensions of mounting flanges for electric motors.* Published by the International Electrotechnical Commission, this recommendation 72-2 specifically covers flange-mounted induction motors that have an outside diameter of flange 9¼ to 22 inches (90 to 1,000 mm). Two series of standard dimensions are recommended: flanges in inch dimensions and flanges in metric dimensions. Priced at $2.40 each. Copies of these three publications may be obtained from the American Standards Association, 10 E. 40th St., New York 16, N.Y.

ARI STANDARDS. The Air-Conditioning and Refrigeration Institute (ARI) has published two new standards for air-conditioning and refrigeration compressors and condensing units. *Refrigerant 12 and Refrigerant 22 Compressors and Condensing Units, 25 Horsepower and Larger, 516-60* establishes recommended definitions, recommended specifications of what constitutes standard equipment, recommended methods of testing and rating, including standard rating conditions, and provisions for safety. This standard is also applicable to the use of Refrigerant 500 if used; price 50¢. *Ammonia Compressors and Compressor Units, 511* applies to enclosed, single-acting, reciprocating ammonia compressors and compressor units, both valve-in-piston and valve-in-head types. Price 50¢. Publication of these standards discontinues the six standards which they replace: ARI Standards 5-12, 5-13, 5-14, 5-15, 5-21, and 5-22. The new standards may be obtained from the Air-Conditioning and Refrigeration Institute, 1346 Connecticut Ave., N.W., Washington 6, D.C.

OTS REPORTS. The Office of Technical Services (OTS) has made the following reports available to the public: *Thermionic Energy Converter, PB 161713* describes fundamental thermionic emitter characteristics and discusses the complex variety of simultaneous processes occurring in the plasma of gas-filled converters; 54 pages, price $1.50. *High Temperature Magnetic Amplifiers (400 Cycles per Second), PB 161762* deals with materials and techniques developed for use in designing a 400-cps magnetic amplifier capable of satisfactory operation over an ambient temperature range of −65 to +500 C during vibrations at frequencies and amplitudes representative airborne environments; 121 pages, price $2.75. *Transistorized Four-Segment Commutator for a Direct-Current Machine, PB 161721* reports a completely transistorized, 4-segment electric commutator capable of switching power loads of up to 600 watts which has been developed for the U.S. Air Force as part of a research program to find a substitute for mechanical commutators in high-speed high-altitude aircraft; 47 pages, price $1.25. *Research in Radiation Damage in Semiconductors, PB 161673* describes a diode resistant to nuclear radiation damage using p-type germanium with resistivity of about 0.20 omh-cm as the base material. *The Soviet Training Program for Automation and Computer Specialists, 60-21187* reports the intensifying training of specialists in automation, computer research, cybernetics, and machine translation in the Soviet Union; 8 pages, price 50¢. All the above publications may be ordered from OTS, U. S. Department of Commerce, Washington 25, D. C.

THE ARRL ANTENNA BOOK. This book is a complete treatise on the theory and practice of antennas for use by amateur radio operators. The 1960 revised edition leads the beginner from the most fundamental aspects of wave propagation through an extensive discussion of antenna theory to descriptions of both simple and complex antenna designs. Written by the headquarters staff of the American Radio Relay League (ARRL), it includes sections on long-wire antennas, rotary beams, antennas for the very high frequencies, and antennas for mobile work, in addition to the fundamentals of all types of antennas. Available for $2 from the American Radio Relay League Inc., West Hartford 7, Conn.

RCA PENCIL TUBES, ICE-219. Information on the design features of pencil tubes, their application to systems, and electrical and mechanical circuit design considerations is given in this booklet for those who work with uhf tubes and circuits. Information on present developmental types and potential uses of pencil tubes is supplied. A tube data section covers the full line of available commercial and military pencil-tube types. Data include dimensions, ratings, operating values, and intended uses as well as photographs of representative tube types. Copies, 50¢ each, may be obtained from Commercial Engineering, Electron Tube Division, Harrison, N.J.

MAINTENANCE HINTS. As electrical maintenance problems change and grow more complex, this newly revised, 672-page handbook will serve both as a guide and information center for electrical inspection and repairs. Among others there are new chapters on safety details and insulations. It is available from Westinghouse Electric Corporation, P. O. Box 398, Trafford, Pa., for $4.

ELECTRONIC ORGAN HANDBOOK. Technicians, musicians, hobbyists, and organ owners will find in this handbook the most comprehensive and current data available on electronic organs. Individual chapters are devoted to descriptions and specifications of specific models and operational theory, schematics, troubleshooting information and tuning instructions are given for organs made by various manufacturers. There are chapters containing general discussion on tuning techniques, including use of the Conn "Strobotuner," and a description of Leslie organ speaker systems. Over 400 illustrations, schematics and diagrams complete the text. It is obtainable from Howard W. Sams & Co., Inc., Technical Book Division, 2201 E. 46th St., Indianapolis 6, Ind. for $4.95.

HANDBOOK OF CHEMISTY AND PHYSICS. Used in research, engineering, education, and business, this revised, 3,400-page 42nd edition is a useful one-source reference volume covering mathematics, physics, and chemistry. New tables include: Diffusion of Metals into Metals, Interplanetary Orbits, Standard Types of Stainless Steel, etc. Among the revised, expanded, and up-dated data are: Atomic Weights, Trade Names of Plastics, Nuclear Spins. It is available from the Chemical Rubber Co., Publications Division, 2310 Superior Ave., Cleveland 14, Ohio, for $12 per copy.

LA

125-400 amps, 600 volts a-c,
250 volts d-c, 2 and 3 poles
IR @ 240 volts a-c: 50,000 amps
Interchangeable Trip
Replaces: KL and J&L breakers

MA

125-800 amps, 600 volts a-c,
250 volts d-c, 2 and 3 poles
IR @ 240 volts a-c: 50,000 amps
Interchangeable Trip
Replaces L, M and LM breakers

J-3032

Are Simple to Specify/Easy to Identify

Any way you look at it, the NEW Westinghouse breakers are the ones you'll want to use.

More information? Contact your nearest Westinghouse representative, Westinghouse distributor your independent panelboard builder . . . or write Westinghouse Electric Corporation, Standard Control Division, Beaver, Pa.

For a large, plastic laminated wall chart of the new breaker line, write Westinghouse.

All Westinghouse AB breakers meet or exceed NEMA and UL specifications.

You can be sure . . . if it's Westinghouse

GTC

UNITIZED
COMMUNICATION
EQUIPMENT for
POWER and INDUSTRY

Effective!
Reliable!
Economical!

1 Highly effective in extremes of ambient noise and temperature.

2 Plug-in units provide ease of installation, expansion and maintenance.

3 Transistors and rugged, industrial type components used throughout.

4 Central control cabinet, costly engineering and fabrication eliminated.

Wherever a highly dependable, voice communication system for use in high noise level areas is needed—you'll find GAI-TRONICS specified by name.

GTC is extremely flexible in application. Write today for a copy of our completely illustrated, descriptive booklet and name of nearest representative.

GAI-TRONICS
CORPORATION
Dept. B
READING, PENNA.

GAI
FOUNDED 1936

A SUBSIDIARY OF
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS

New & Improved Products

(Continued from page 20A)

Thermocouple Reference . . .

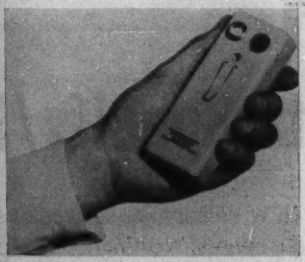
Development of a precision, miniature, solid-state, electronic thermocouple reference designated *TR-100*, provides a constant reference temperature of 100 C, ±0.1 C with a 10-channel uniformity of ±0.1 C and a maximum drift of less than 0.25 C over an ambient temperature range of −55 C. to +85 C. Low power consumption, small size, and light weight make it ideal for airborne applications. *Genistron, Inc., 6320 W. Arizona Circle, Los Angeles 45, Calif.*

U-Shaped Wedges . . .

Three new U-shaped electric motor stator wedges in widths of $\frac{5}{16}$, $\frac{11}{32}$ and $\frac{3}{8}$ inch have been added to the present line, making a total of 11 widths now available from $\frac{3}{16}$ to $\frac{1}{2}$ inch. Used as insulation for class B and F motors, a special 1-piece molded construction of polyester reinforced with woven Fiberglas will provide higher strength and easier driving than wood or fiber wedges. *The Glastic Corp., 4321 Glenridge Rd., Cleveland 21, Ohio.*

Pocket Alarm . . .

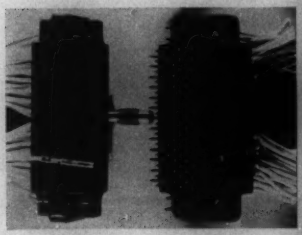
Little larger than a pack of cigarettes, this 5-ounce personal alarm will provide instant warning for all persons working with radio isotopes or near gamma and x radiation. The instrument provides a violent crackle when radiation is as low as 3 milliroentgens per hour or an audible



clicking at even lower radiation levels. At 100 milliroentgens per hour the crackle turns into a violent buzz, while 1 roentgen per hour will produce a shrill, action-demanding whistle. *Gelman Instrument Co., 106 N. Main St., Chelsea, Mich.*

Universal Connectors . . .

Designed for solderless installations, these new *MS* connectors employ removable pins and sockets. Various standard configurations of basic con-



nectors, pins, and sockets are available to accommodate wire gauges from no. 8 through no. 22 including coaxial cables. The connectors also feature removable precision centering hardware. *Hughes Aircraft Co., P. O. Box 90904 Airport Station, Los Angeles 45, Calif.*

Waterproof Tow Cable . . .

For use in supporting sonar, target buoys, and submarine research gear, this flat, flexible, stainless-steel braided tow cable is nonkinking and will withstand a breaking strength up to 3,000 pounds. Twenty conductors transmit signals of all types and levels. A tough neoprene jacket makes the cable completely watertight. *Boston Insulated Wire & Cable Co., 65 Bay St., Dorchester, Mass.*

Electronic Pupillograph . . .

Limited production is now underway on an electronic device for recording pupillary movement that shows the presence of lesions within the nervous centers and pathways of pupillary control. Until 1947, recording and analyzing pupil reflexes involved the complex use of film and manual measuring techniques. During the next 10 years film was employed with an electronic measuring device, but the techniques were still too complex for general clinical use. The first electronic method based on closed-circuit television was also abandoned as being too complex, but the fundamental approach using the measurement of time consumed to scan the diameter of the pupil was retained and incorporated in the present unit. *General Precision, Inc., 63 Bedford Rd., Pleasantville, N.Y.*

(Continued on page 32A)

Professional Engineering Directory

Professional Engineering Directory Card 1" or 2" 12 times $180.00

ELECTRICAL TESTING LABORATORIES, INC.
2 East End Avenue, New York 21, N. Y.
Electrical, Electronic, Environmental, Photometric and Chemical Laboratories
Testing, Research, Inspection and Certification

THE KULJIAN CORPORATION
Engineers • Constructors • Consultants
POWER PLANT SPECIALISTS
(Steam, Hydro, Diesel)
Utility • Industrial • Chemical
1200 NO. BROAD ST., PHILA. 21, PA.

MINER and MINER
Consulting Engineers
Incorporated
Greeley, Colorado
Littleton, Colorado
Tucson, Arizona Phoenix, Arizona

INTERNATIONAL ENGINEERING COMPANY, INC.
Engineers
Investigations—Reports—Design
Procurement—Field Engineering
Domestic and Foreign
74 New Montgomery St.,
San Francisco 5, Calif.

MEASUREMENTS
A McGraw-Edison Div.
RESEARCH & MANUFACTURING ENGINEERS
Specialist in the Design and Development of Electronic Test Instruments
Boonton, N.J.

SVERDRUP & PARCEL ENGINEERING CO.
Engineers—Architects
Electrical Studies & Planning
Transmission—Distribution—Control
Power Plants—Industrial Plants
Test Facilities—Development—Design
Supervision of Construction
St. Louis San Francisco

PETER F. LOFTUS CORPORATION
PFLC ESTABLISHED 1923
Design and Consulting Engineers
Electrical • Mechanical
Structural • Civil
Nuclear • Architectural
FIRST NATIONAL BANK BUILDING
Pittsburgh 22, Pennsylvania

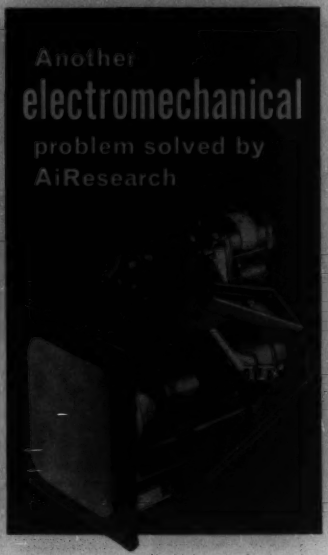
CONSULT THIS DIRECTORY
when in need of specialized engineering service

JACKSON & MORELAND, INC.
Jackson & Moreland International, Inc.
ENGINEERS and CONSULTANTS
Electrical—Mechanical—Structural
Design and Supervision of Construction
-:- for -:-
Utility, Industrial and Atomic Projects
Surveys—Appraisals—Reports
Machine Design—Technical Publications
BOSTON WASHINGTON NEW YORK

PROFESSIONAL SERVICES
Over a wide range are offered
by these cardholders

MULTI-AMP Division
MULTI-AMP ELECTRONIC CORPORATION
Designers • Engineers • Builders
Portable Electric Test Equipment
Field and Laboratory Instruments; Load Boxes
For low-voltage testing and calibrating of circuit breakers, protective and overload relays, reclosures, watthour meters, fuse links.
467 B Lehigh Ave. Union, N. J.

SARGENT & LUNDY
ENGINEERS
Consultants to the Power Industry
STUDIES • DESIGN • SUPERVISION
140 South Dearborn Street, Chicago 3, Ill.



This ram air scoop is another example of AiResearch's ability to design and integrate structural and electromechanical systems for control functions.

Through its use, air is provided for emergency cabin pressurization and the cooling of electronic components. The unit is composed of a retractable aluminum ram air scoop, extended and withdrawn by a 400 cycle rotary actuator, a self-contained 350 watt heating element and an integral check valve.

The most experienced company in the development and production of control systems for airborne and ground use, AiResearch has the ideal facilities and know-how to handle problems concerning electromechanical systems and components of all types for aircraft, ground handling, ground support and missile systems.

OTHER ELECTROMECHANICAL COMPONENTS AND SYSTEMS

AC and DC Motors, Generators and Controls • Static Inverters and Converters • Linear and Rotary Actuators • Power Servos • Hoists • Temperature and Positioning Controls • Sensors • Programmers • Missile Launchers • Radar Positioners • Power Supplies • Williamsgrip Connectors

Your inquiries are invited.

THE GARRETT CORPORATION

AiResearch Manufacturing Division

Los Angeles 45, California

New & Improved Products

(Continued from page 30A)

Static Voltmeter . . .

A new tubeless instrument that measures static charges from 0 to 5,000 volts under actual production conditions uses a roller electrode to make precise measurements of specific

charges on individual filaments and sheets as well as field measurements. Made in Switzerland, the Rothchild static voltmeter permits simultaneous measurement and recording of charges over eight ranges from 1 to 5,000 volts. This broad sensitivity makes it useful in production line operations and in the laboratory. *Fabrionics Corp., Box 521, Huntington, N.Y.*

Constant Wattage Ballast . . .

This 400-watt 2-lamp parallel mercury transformer features a new constant wattage circuit that provides electrical independence between the lamps. Each lamp is provided with its own series capacitor. Interaction between lamps is negligible, thus failure of one lamp will not significantly affect the operation or light output of the remaining lamp. Starting voltage assures positive starting of *H-I* type lamps down to —20 F. *Sola Electric Co., Busse Road at Lunt, Elk Grove, Ill.*

Marker Caboose Lights . . .

Constantly flashing transistorized electric red lamps have been developed to take over the function of the twin marker lights used on the rear of freight train cabooses. The new flashers, which light up every second for 1,200 hours on two small batteries, employ a special lamp bulb filament controlled by a transistor causing it to flash. The brilliant red blinkers are visible over a greater distance than the present steady lights and more clearly mark the rear of the train. *The Pennsylvania Railroad, Philadelphia 4, Pa.*

New Oil Circuit Reclosers . . .

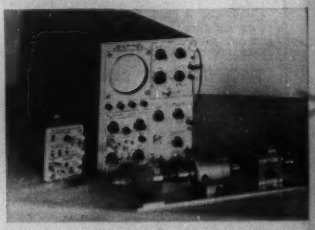
Two new circuit reclosers featuring electronic controls provide a choice of two fast and four retarded time-current curves which can be used in a sequence of one to four operations to lock-out. Minimum-trip settings range from 100 to 1,120 amperes with different reclosing intervals obtainable. Type *RE* is rated at 400 amperes continuous up to 4,000 at 14.4 kc. Type *WE* is rated at 560 amperes continuous, and will interrupt up to 8,000 amperes at 14.4 kv. Fault currents can be cleared in 2½ cycles or less. *Line Material Industries, Milwaukee 1, Wis.*

Dual-Phase Power Plant . . .

A new development now permits factory-modified standard line models of gasoline-driven electric generating plants to give full-rated power in both single- and 3-phase current. Designed to provide a more flexible unit, these *M-G* sets will deliver either 120/240 single-phase or 120/208 3-phase output. Developed primarily for telephone utilities where repeater stations and independent exchanges demand uninterrupted service on both types of power, their use may also be extended to commercial and industrial applications lending themselves to this type of power. *D. W. Onan & Sons Inc., 2515 University Ave., S. E., Minneapolis 14, Minn.*

Rotan System . . .

Designed to study rotation-associated phenomena in machinery, the two Rotan units adapt an oscilloscope



to provide horizontal trace deflection proportional to angular displacement of a rotating shaft. The system generates a horizontal sweep representing shaft angle at speeds from essentially 0 to 20,000 rpm. Transduced data, such as velocity, pressure, acceleration, or vibration, appears on the cathode-ray tube screen correctly referenced to this instantaneous angular position. *Tektronix, Inc., P. O. Box 500, Beaverton, Oreg.*

Industrial Notes...

Neff Instrument
Duarte, Calif. . .

Neff Instrument Corporation has moved to new, larger facilities at 1088 E. Hamilton Road, Duarte, Calif.

Spokesmen for the company said that the new plant will enable Neff to produce an increasingly diversified line of both ground and airborne signal conditioning equipment. Design features of the new building include tilt-up concrete walls, and laminated wood beams. Reception and conference rooms look out on tropical gardens screened by a concrete grill suspended in a tubular steel frame.

Gilliland Instrument
Oakland, Calif. . .

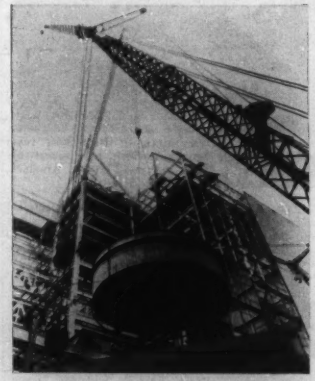
An image translator to measure photographic traces of missile trajectories is being developed for the Army by Gilliland Instrument Company. Plans for the system call for installation at White Sands Missile Range early in 1961. The $100,000 system will measure X and Y co-ordinates of point or line images on photographs to within one micron. A semiskilled operator will be able to measure a trajectory in minutes, rather than hours. Output is in the form of punched cards carrying frame identification and image X-Y co-ordinates, subsequently processed by a digital computer programmed to yield missile flight path information.

Melpar, Inc.
Fairfax, Va. . .

Specially built scale models of tactical United States military aircraft are used at Melpar, Inc., subsidiary of Westinghouse Air Brake Company, to test the electrical characteristics of antenna designs prior to production. Use of the scaled-down aircraft models with proportionally scaled miniature antennas, and transmitted energy scaled upward in frequency by the same ratio by which the aircraft model is scaled downward, enables the engineers to duplicate characteristics of full-scale antennas for actual flight. In test operations, signals are transmitted to a pylon-mounted aircraft model from a stationary tower simulating actual transmission to full-sized aircraft in flight. Coaxial cable mounted within the pylon permits charting of signals received by the model in various flight attitudes, revealing the effect of aircraft surfaces on antennas. The model scale is chosen so as to optimize the antenna size for maximum convenience in the laboratory research and development stages.

Wisconsin Electric
Oak Creek, Wisc. . .

Three Ljungstrom air preheaters are being installed at the Oak Creek plant of Wisconsin Electric Power Company to serve the new No. 6



boiler unit. The preheaters will recover about 280 F of heat at rated load which would normally be wasted. Weighing about 580,000 pounds each, the new units will be used on a 1,780,000-pound-per-hour pulverized coal fired boiler. When placed in operation, the preheaters, manufactured by The Air Preheater Corporation of Wellsville, N. Y., will receive incoming air at 190 F and preheat it for combustion to about 510 F. This is accomplished through continuous regenerative heat recovery which removes heat from exhaust gases being emitted from the boiler at 550 F, thus reducing stack temperature to 270 F. The exhaust gases pass through the preheater elements which, after absorbing the waste heat, rotate and release the contained heat to the incoming combustion air.

ARPA
Washington, D.C. . .

A special Technical Advisory Group for Ballistic Missile Defense has been set up in co-operation with the Massachusetts Institute of Technology Lincoln Laboratory, Stanford Research Institute, Cornell Aeronautical Laboratory, and the Willow Run Laboratory of the University of Michigan to provide advice and recommendations on the various aspects of Project DEFENDER of the Advanced Research Projects Agency (ARPA). The advisory group will be composed of representatives selected from the laboratories involved in ballistic missile defense research under ARPA contract. Its primary purpose will be to advise ARPA's Assistant Director for Ballistic Missile Defense, A. M. Rubenstein. In this way, exchange of information and ideas between technical management personnel in ARPA and research personnel in the field will be facilitated. The Advisory Group is expected to concern itself with technical review, evaluation, and the provision of recommendations on the various aspects of the ballistic missile defense problem with which its member laboratories are concerned, as well as with various other problems.

Sylvania Electric Products
Emporium, Pa. . .

Sylvania Electric Products Inc., a subsidiary of General Telephone & Electronics Corp., recently began construction on a new electron tube research and development center. First stage of the construction program is a 42,000-square-foot facility to house research activities on "Sarong," cathode coating and various types of "stacked-tubes." A portion of the new structure will be made available for the division's chemical development research. Occupancy is scheduled for mid-1961.

Additional buildings, still in the planning stage, are scheduled for completion in 1963.

(Continued on page 40A)

ENGINEERING SOCIETIES PERSONNEL SERVICE, INC.

(Agency)

New York	Chicago	San Francisco
8 West 40th St.	29 East Madison St.	57 Post St.

These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the national societies of Civil, Electrical, Mechanical, Mining, Metallurgical, Petroleum, and Chemical Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 60% of 1st month's salary, if a non-member, or 50% if a member. Also, that you will agree to sign our placement fee agreement which will be mailed to you immediately, by our office, after receiving your application. In sending applications be sure to list the key and job number.

When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

A weekly bulletin of engineering positions open is available at a subscription rate of $4.50 per quarter or $14 per annum, payable in advance.

MEN AVAILABLE

New York Office

ADMINISTRATIVE ENGINEER, E.E., 20 years' industrial and commercial consulting engineering. Project engineer and chief electrical engineer for large firm. Organizer, service sales, cost control, coordination, scheduling, job evaluation, construction. Capable of taking full responsibilities for complete operation. Salary, $15,000-$18,000 a year. Location desired, USA. E-214.

PLANT OR ELECTRICAL ENGINEER, B.S.E.E., P.E., N.J. Over 20 years' experience as an engineer in industrial and railroad plants, planning, design, construction, operation and maintenance of all plant facilities and many types production equipment. Salary, $10,800 a year. Location, Eastern U.S. E-215.

Chicago Office

ELECTRICAL ENGINEER, B.S.E.E., 44. Experienced in electric distribution and transmission and telephone systems design, construction, operation. Over seven years' executive experience with medium size consulting firm offering diversified services. Salary, $10,000 and up. Location Open. E-2015-Chicago.

CHIEF ENGINEER OR ENGINEERING MANAGER, M.Sc.E.E., 46. 18 years' professional experience in design and development of fractional HP motors: DC for automotive applications, AC: shaded pole, split ph, and 3 ph. Initiative and curring-out on development. Sale department proposals evaluations. Cost reduction problems. Supervision of standard designs. Salary, $15,000 a year. Location, Any in USA. E-2014-Chicago.

ELECTRICAL ENGINEER, ELECTRICAL SUPERVISOR, BSEE, 64. 40 years' experience in electrical engineering field, later years' in supervision capacity. Construction, maintenance and operation steam, hydro and diesel power plants, distribution substations, three phase and single phase power and distribution transformers, primary and secondary three phase, 60 cycle transmission lines to 33,000 volts. Motor and transformer repair. Salary, $8000-$9000 a year. Location, Any. E-2015.

ELECTRICAL POWER SYSTEMS ENGINEER, E.E., 55. Registered in Michigan, Marvland, Ohio. 13 years' engineering consulting, electric power five years', industry, rubber. 12 years' public utility, distribution. Prefer small electric utility. Salary open. Location, South or Southwest. E-2012-Chicago.

INDUSTRIAL SALES MANAGEMENT, E.E. graduate and Sales and Management courses, 36. 11 years' selling to industry, 8 years' in top management as sales manager later V.P. and Director of Company. Sales experience to large companies on top level high dollar volume accounts. Salary, $18,000 plus bonus or included. Location not important. E-2011-Chicago.

TRANSFORMER ENGINEER, B.S. physics and engineering, 39. Six and a half years' power transformer design, involving both shell and core form construction. Five years' and five months' varied transformer development assignments. Capable report writer. Adaptable to wide range of projects and reliable, strong background. Salary, $9000 a year. Location, Any. E-2010-Chicago.

San Francisco Office

OPERATIONS SUPERINTENDENT, 48. Twenty-one years experience charge of engineering, operation, maintenance, planning, construction, budget preparation, public and labor relations for electric public utilities. Five years design of high tension switch equipment for manufacturer. $9600. Pref: Latin America, Southwest. Home: Mexico. Se-1888.

FIELD ENGINEER, 38, EE. Broad electrical background with experience in electric power distribution, supervision, construction, industrial power sales and street lighting. Registered in Wisconsin. Active in engineering societies. Public relations minded. $8400. Prefer Northern California. Home: Wisconsin. Se-1869.

SYSTEMS PLANNING, OPERATIONS, EE, 44. Over twenty years responsible charge of electric utility systems planning economic and operational studies including relaying, automation of gas transmission stations for an engineering consultant. $15,000. Prefer East or Midwest. Home: Pacific Northwest. Se-1764.

DISTRIBUTION, TRANSMISSION ENGINEER, EE, 49. Eighteen years in public utility engineering, electric distribution, transmission, substations, underground, operations, public contact, training and supervision, cost estimating. Salary open. Prefer: Overseas. Home: Florida. Se-1724.

PRODUCTION ENGINEER, Engrg.BusA, 26. Five years experience with aircraft and industrial plumbing hardware manufacturer; product engineering for flex hose, fittings, self-seal couplings. Review and proposal to customer and MIL specifications, drawings. Customer and vendor contact. Some supervision experience. $8500 up. Any location. Home: California. Se-1490.

PRODUCT PLANNING, MARKET RESEARCH, EE, MBA, 31. Seven years in the design and marketing of military and commercial electronics. Currently manager of product planning and market research with large auto manufacturer. $16,000. Any location. Home: Wisconsin. Se-212.

SALES ENGINEER, EE, 58. Twenty years experience electrical instruments and equipment sales. Desire progressive organization. $8400. Prefer: California. Home: Missouri. Se-178.

ENGINEERING MANAGER, PhD EE and ME, 55. Organizing ability, experience on executive level, solid knowledge in engineering, contacts to leading electrical engineering firms here and abroad. Originality. Energetically follow through. Cost and quality conscious. Want relocate for family reasons, to dry, warm climate. $20,000. Home: New Jersey. Se-172.

UTILITIES ENGINEER, EE, 41. Fifteen years experience in charge of office and field design of electric transmission and distribution lines and associated equipment, plans and specifications, studies, for utilities, consultants. One year experience sales of motors, controls, lighting fixtures for manufacturer's representative. $8400. Prefer San Francisco Bay Area. Home: San Francisco Peninsula. Se-134.

DESIGNER, EE, with control and electronic option, 28. Three years experience; one and one-half years design, test of electrical controls, instrumentation, optical systems on precision heavy machinery for a manufacturer; one and one-half years surveys and systems adjustments of electrical distribution for a utility. Interest in servos, instrument systems, circuitry. Prefer San Francisco Bay Area or West Coast. Home: Oregon. $7200 up. Se-114.

PROJECT ENGINEER, EE, 36. Eleven years varied experience, contract administration, design including power and lighting and control, supervision of equipment installations, customer relations. $9000. Will relocate West of Mississippi. Home: Idaho. Se-108.

PLANT OR PROJECT ENGINEER, ME, EE, 38. Trades training, fourteen years experience in heavy power, control, instrumentation including staff direction, costs, scheduling of designs, construction, operation and maintenance of power plants, substations and transmission and plant distribution. $9600-$12,000. Prefer: West Coast. Home: California. Se-102.

POSITIONS AVAILABLE

New York Office

ELECTRICAL ENGINEER, experience in diesel, turbine driven generators, switchboards and power distribution medium sized AC and DC motors. Some electronic desirable but not essential. Salary, $8000-$10,000 a year. Location, central East Coast. W9796.

SALES ASSISTANT, with electrical engineering training and electrical equipment experience to assist in preparation of quotations, estimates, orders and deliveries. Must be familiar with New York area. Salary, $5200-$6500 a year. W9786.

ELECTRICAL ENGINEER, graduate E.E., with a minimum of five years' experience for system analysis and design involving the application of motors, generators, controllers and servo-mechanisms; preparation of technical proposals, design studies and project engineering on hardware contracts. Salary, $9000-$12,000 a year. Company pays placement fee. Location, Northern N.J. W9785.

ENGINEERS. (a) Senior Product Design Engineer, with a minimum of eight years' product design background, for directing the design of major components, principally servomechanism. To work from design directives, specifications, precision eelctro-hydraulic products for volume production. Salary, $10,000-$12,000 a year, plus management profit sharing. (b) Production Engineer, B.S.M.E. or B.S.E.E., with five to ten years' in one or more of the following areas: Product engineering and design, production engineering, servomechanisms, hydraulic components and/or controls. To develop procedures for production testing, assembly and rework, maintain liaison with production specs. and standards. Salary, $8000-$11,000 a year, plus profit sharing. (c) Prototype Engineer, B.S.M.E. or E.E., with a minimum of two years' background in hydraulic, pneumatics or electronics necessary. Experience in design, instrumentation, controls and liaison highly desirable. To assume responsibility for revising customer specs. to determine internal components. Salary, $7500-$10,000 a year, plus profit sharing. Company pays placement fees. Location, Buffalo, New York. W9784.

CLASSIFIED ADVERTISING

For help and situations wanted, $2.25 per line, minimum 5 lines, maximum 30 lines. Sale and purchase of used machinery, etc., $3.00 per line, not available to dealers. Address orders to: Classified Section, ELECTRICAL ENGINEERING, 6th Floor, 33 West 39th Street. New York 18, N. Y.

When answering an advertisement, send all replies to box number specified, c/o ELECTRICAL ENGINEERING, 6th Floor, 33 West 39th Street, New York 18, N. Y., unless other address is given.

POSITIONS OPEN

PROFESSOR OR ASSOCIATE PROFESSOR of Electrical Engineering to teach and do research in the field of communications. Should have Ph.D., teaching and research experience. Write Box 56.

GRADUATE ASSISTANTSHIPS are available at a university in the Southeast for September, 1961. Assistants may obtain the Master of Science degree in Electrical Engineering in twelve months. Tuition free. Write to Box 99.

TEACHING POSITION IN ELECTRICAL ENGINEERING open to teach machinery and other undergraduate subjects. Also, some graduate courses at night. MS or Ph.D. preferred. Appointment February or September. Write to Head, Electrical Engineering Department, University of Akron, Akron 4, Ohio.

ELECTRICAL ENGINEERS with B.S. Degree. Recent graduates: rapidly expanding public utility has openings for ambitious young men in the electric transmission and distribution field. Substation design, voltage regulations, system stability, protection and line construction are only a few of the fields open to qualified men with a desire to advance. Write qualifications to: Employment Office, San Diego Gas & Electric Company, P. O. Box 1831, San Diego 12, California.

ELECTRICAL ENGINEER GRADUATE, to 45, with power experience for supervisory position in the Electrical Department of a large industrial plant. Must be U.S. Citizen. Location, West Texas.

ENGINEERS—COLLEGE POSITIONS. All sections U.S. all fields of engineering. Openings for B.S., M.S., and Ph.D's. Excellent salaries. Send qualifications to Cline Teachers Agency, Box 607, East Lansing, Michigan.

OVERSEAS. Robert College, in Istanbul, Turkey, presents a challenge in education in a vital part of the world. West and Middle East are contributing side by side to the development of a young and vigorous nation. Opportunities are available in engineering, business administration and economics, the sciences, and the humanities. Graduate degrees required. Address inquiries to Dr. Howard P. Hall, Dean of Faculty, Robert College, Bebek Post Box 8, Istanbul, Turkey; with copy to the Near East College Association, 548 Fifth Avenue, New York 36, New York.

RESEARCH PROFESSOR. Electronics engineer with B.S. or M.S. degree plus radar design experience to conduct research in weather radar. Salary dependent on qualifications and experience. Contact H. W. Hiser, Head, Radar Meteorological Research, Marine Lab., University of Miami, Coral Gables, Florida.

ELECTRONIC ENGINEER with experience in electronic circuits, measuring instruments urgently needed. Good working conditions. Excellent chance for advancement. Ad-Yu Electronics Laboratory, Inc., 249 Terhune Avenue, Passaic, N. J., GRegory 2-5622.

POSITIONS WANTED

DESIGN ENGINEER, under 35, B.E.E. Seven years experience in motors and generators. Also extensive background in maintenance, repair and installation. (Marine & Industrial). Desire challenging position utilizing experience and education. Write to Box 111.

(Continued on page 43A)

Discover the advantages of GLASTIC®!

Price of GLASTIC is coming down —phenolic still going up

These coins tell the story of lower material and fabrication cost. Your parts may now cost half as much in Glastic as in phenolic. Since 1952, Glastic prices have come down as much as 44%*. Phenolic prices recently rose again.

Consider all the cost-saving advantages of Glastic fiber glass reinforced polyester. Punchability, even in thicker sections, reduces fabrication costs. Up to 20 times higher impact strength allows the use of less material. Dimensional stability in heat and moisture permits more compact assemblies.

Re-examine your phenolic parts. When you specify laminates or fabricated parts, compare Glastic. Check properties *and prices*. Write us for samples and a chart that compares Glastic with paper and canvas phenolic. Or, send us your prints for our recommendations.

*Glastic general purpose Grade TS now priced at $.58 per lb. in 300 lb. lots.

GLASTIC
GLASS REINFORCED PLASTIC
T.M.

THE GLASTIC CORPORATION

4312 Glenridge Road • Cleveland 21, Ohio

Visit Glastic Booth No. 103-104 at the Insulation Conference, Chicago, Dec. 5-8.

Industrial Notes

(Continued from page 33A)

Packard Bell Electronics
Los Angeles, Calif. . .

Packard Bell Electronics Corp. has been awarded a contract by the Applied Physics Laboratory of John Hopkins University to produce a key portion of TRANSIT, a satellite-controlled navigation system under development for the U. S. Navy. The system will be designed around the *pb250* general purpose computer developed by the company's Computer Division. The equipment to be supplied by Packard Bell Computer is a preprototype of the type of digital equipment required for shipboard use. It will enable Applied Physics Laboratory researchers to evaluate and refine the TRANSIT system for universal application.

Camblock Corp.
Natick, Mass. . .

Camblock Corporation has relocated its entire facilities from New

York City to Natick, Mass. The corporation now occupies a new, modern building with 10,000 square feet of space.

Continental-Diamond
Newark, N.J. . .

Continental-Diamond Fibre Corp. (CDF) has successfully completed experiments demonstrating that a group of flame and heat resistant coatings can be bonded to and are compatible with sheets, tubes, and molded shapes of many grades of CDF industrial and high-temperature plastics. The intumescent coatings which have been applied to CDF plastics are now being used to protect umbilical cables, launching pads, and electrical components during missile launchings. The coatings are put on by ordinary brush or spray techniques, and are air-drying at room temperature. No heating is necessary to complete the bonding process.

Westinghouse
Pittsburgh, Pa. . .

A $6 million contract to weather-condition a complete suburb—first in the nation to be completely air conditioned—and to supply kitchen and laundry appliances for its homes, has been signed by Westinghouse Electric Corporation and Levitt & Sons, Inc. Westinghouse will supply the heating, air conditioning, and appliance products for the 4,500-home Belair suburb the Levitt organization is building in Maryland, between Washington and Baltimore. The first exhibit homes were opened for public inspection in October. The value of the kitchen and laundry appliances in each house will range from $1,000 in the $14,990 4-bedroom "Cape Cods" to more than $1,500 in the top models. The contract calls for more than 20,000 appliances.

NRC
Newton, Mass. . .

Adaptation of electron bombardment heating sources to standard and special vacuum coaters for research into the evaporation of ultra-pure metals and alloy systems, as well as for depositing high-temperature materials such as zirconium, tantalum, and tungsten, has been announced here today by NRC Equipment Corporation, a subsidiary of National Research Corporation. According to the company, any of its standard coaters can be supplied with electron bombardment evaporation sources. Evaporation paths can be controlled by the relative position of the gun and of the metal to be evaporated. The latter can be mounted either as an ingot or a button on a copper, water-cooled support. The gun can be located either on top or on the side of the chamber and is rated at up to 6-kw. A variety of power supplies is available to meet customer requirements. The model *3144* coater is available with either an 18- or 24-inch mild steel or stainless steel bell jar. It is equipped with a new high-speed 6-inch fractionating diffusion pump. Rotary gas ballast mechanical pumps of 15- to 30-cubic-feet-per-minute rating are used for rough pumping and back-up, depending on performance requirements. Top operating temperature is practically unlimited, and the bulk material can serve as its own container, thus making it possible to evaporate almost any material, including those of especial interest for electronic research on thin films, for investigation of the bulk properties of high-temperature alloys, or simply for coating missile and industrial components with highly corrosion or heat resistant surfaces.

Philco
Philadelphia, Pa. . .

The Philco-*2000*, an advanced commercial electronic data-processing system, has been accepted by the U.S. Atomic Energy Commission's Knolls Atomic Power Laboratory (KAPL) in Schenectady, N.Y. The magnetic tape system of the Philco-*2000* uses a high-speed tape transport. It can read and/or write, using any 2 of 16 tape units at an instantaneous rate of 180,000 alpha numeric characters per second and 312,500 decimal characters per second, while computation is proceeding. The punched card system utilizes the fastest card reader available, reading 2,000 cards per minute, and the high-speed printed operates at 900 lines per minute. The system has the ability to sort 100,000 records from random order into sequence in 19.5 minutes. Contained in the Philco-*2000* are more than 2 million individual parts, including 60,000 transistors; 100,000 resistors; 50,000 condensers; and more than 790,000 feet of wire.

Autonetics
Downey, Calif. . .

A quality, reliability, and standards technical division has been established by Autonetics, a division of North American Aviation, Inc. The division will provide a central focal point for issuing and monitoring central policies and procedures for quality control, reliability, and standards throughout the firm. Fully equipped laboratories are available for evaluation and quality control of materials, processes, and components used in Autonetics' products. A number of aircraft are operated to provide airborne test environment.

The Martin Co.
Baltimore, Md. . .

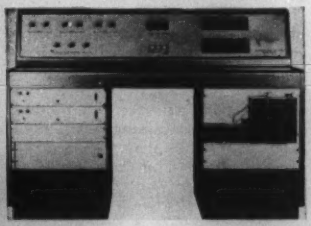
The Pennsylvania State University has approved an arrangement under which part of the University's nuclear research facilities at Quehanna, Pa., will be made available to The Martin Company for work in the development of isotopic power. The firm will use five large, well-shielded "hot cells" in which the radioisotopes can be handled safely by means of mechanical manipulators prior to being sealed inside the fuel blocks and loaded into test generators. The cells vary from 12 to 15 feet in height and total more than 300 square feet in area. The agreement is contingent upon Atomic Energy Commission approval of a license to carry out the work involved.

Du Pont de Nemours
Wilmington, Del. . .

E. I. Du Pont de Nemours & Company has developed a new line of resistor compositions offering varied resistance values to provide greater flexibility in miniaturized circuitry. The result of a 5-year research effort, the new compositions are available in three resistance values (500; 3,500; 10,000 ohms per square per mil thick film) which can be blended to obtain intermediate values. Applied to ceramic dielectric bases by ordinary dip, brush, or stencil screen techniques, the composition is then fired in a normal atmosphere to obtain a durable surface. Electrical properties of the resistors are reproducible.

Monitor Systems, Inc.
Fort Washington, Pa. . .

Monitor Systems, Inc. has completed a Data Acquisition System for Fort Belvoir. This equipment will enable the Mine Detection Branch of



the Engineering Research and Development Laboratory to speed up its evaluation of mine detection equipment and to free engineering manpower for other programs.

ITT
New York, N.Y. . .

An agreement providing for the engineering, manufacture, and marketing of exploding bridgewire systems, for applications in the missile and space fields and for industrial use, has been entered into by the Industrial Products Division of International Telephone and Telegraph Corporation (ITT) and McCormick Selph Associates, Hollister, Calif. McCormick Selph Associates will be responsible for overall marketing of the systems. The ITT division will provide XBS electronic power supplies and special cabling and will participate in the marketing function.

(Continued on page 42A)

Power Engineers

Now you can work in the design of Aerospace vehicle electric generation systems

Utility and industrial engineers, and generation transmission and protective engineers with BSEE and MSEE degrees are needed immediately with experience in:

Transmission line calculations
Fault analyses
Protective network design
Analogue computers
Power conversion devices
Generation systems parameters

Positions in the following fields are also available to qualified engineers with BSEE and MSEE degrees:

Design Circuits of functional systems for power generation, monitoring and protective circuitry, distribution networks, armament controls, landing gear actuation systems, and a host of operational systems.

Circuit Analyses encompassing symmetrical components, La Place transforms, Fourier Series, computer evaluations, plus others.

Development and Testing electrical and electronic equipment—from microelectronic units to 1000 kilowatt power components.

Integrated Installation of components and systems.

For more information please write to: Mr. D. M. Bowman, Engineering Personnel, North American Aviation, Inc., Los Angeles 45, California.

LOS ANGELES DIVISION
NORTH AMERICAN AVIATION

Industrial Notes

(Continued from page 41A)

Goodyear
Akron, Ohio . . .

The Maritime Administration will negotiate a contract with Goodyear Aircraft Corporation for the development of a radar unit that will eliminate or minimize the possibility of ship collisions at sea. The project is part of a continuing research and development program to improve efficiency and safety aboard American merchant vessels. Work on the experimental radar data computer will be carried out at Goodyear's Litchfield Park, Ariz. installation. The computer will be designed to plot simultaneously the projected courses of as many as 10 ships, and to sound an alarm when collision distances fall below predetermined minimums. It will also indicate an appropriate maneuver to enable the equipped ship to avoid all vessels in the area.

I-T-E Circuit Breaker
Philadelphia, Pa. . .

The first of 160 huge antenna dishes, designed to give the North Atlantic Treaty Organization (NATO) the world's most extensive scatter-type radio communications system, were recently completed in Turkey. The net-

work, appropriately named "Ace High," will link member nations from southern Turkey to northern Norway. Forward - scatter transmission — the beaming of ultra-high frequency signals at tropospheric or ionospheric layers which, in turn, reflect the energy groundward to predetermined points—will be used. Fast and reliable, this type of communication can be utilized far beyond the horizon—up to 250 miles by tropospheric scatter and 1,300 miles by ionospheric. Specially designed for NATO by the Special Products division of I-T-E Circuit Breaker Company, the solid steel antennas range from 30 to 60 feet in diameter. Installation of the $6 million antenna project is expected to be completed in 1961.

Collins Radio Company
Cedar Rapids, Iowa . . .

A corporate research division to advance basic research in electronics is planned by Collins Radio Company. The new division will be located near the University of California facilities, offering advantages to both the research division and the university staff. Location sites under consideration include La Jolla and Newport Beach. Among the fields the division will work in are solid-state physics, electromagnetic wave propagation, thermoelectric phenomena, information theory, network synthesis, radio astronomy, and digital processing.

Precision Multiple Controls
Ridgewood, N.J. . .

All exterior illumination for Garden State Plaza, N. J., said to be the world's largest shopping center, is triggered by a pair of Precision tubeless controls weighing less than 2 ounces each. The miniaturized photoelectric multiple controls automatically turn on the Garden State Plaza's 400 parking area lamps and 1,000 canopy lights whenever natural light drops below 5 foot candles. In this installation, the two multiple controls are mounted atop the central cooling tower. One unit triggers canopy lights spaced 12 feet apart on the all-weather overhangs that distinguish all shops, restaurants, and public buildings. The second unit actuates 10 lamps on each of 46 parking area poles. All perimeter and service area luminaires remain on until sunrise, depending upon the Precision control for automatic turn-off when natural light rises above 2.5 foot candles. The balance of the parking lot lamps are extinguished by a standard time clock shortly after store closing.

Texas Instruments
Dallas, Texas . . .

W. F. Joyce, vice-president in charge of the Apparatus Division, Texas Instruments Inc., has announced the establishment of the Walter F. Joyce Foundation, a nonprofit activity for the study and investigation of geophysical and geochemical phenomena. The initial grant of approximately $60,000 will be made by the Foundation to the Massachusetts Institute of Technology for the study of radon gas by Prof. R. D. Evans of the Physics Department. Field sampling, analysis of soil gas and air, and interpretation of experimental results will be carried out under the initial program authorized by the grant.

Bailey Meter Co.
Cleveland, Ohio . . .

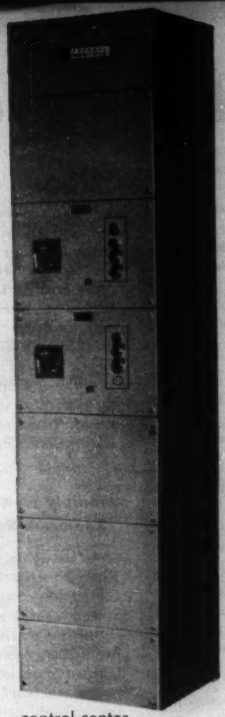
A contract for a new solid-state Bailey *750* information system with magnetic drum programming and a digital computer for performing all computing functions has been received by Bailey Meter Company from the Gulf States Utilities Company. The system will be installed at the Sabine Power Station in Orange County, Texas. Cost of the new system is approximately $225,000. The contract also specifies the use of Bailey Meter transmitters, measuring equipment, and electric MINI-LINE gages and recorders, to bring the contract total to an amount in excess of $300,000.

Emerson Radio
Jersey City, N.J. . .

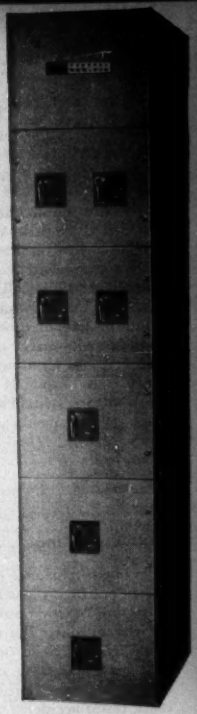
The Technical Products Division of Emerson Radio & Phonograph Corporation has received a patent for a new type of inductive tuning device which was developed at its engineering laboratories. The tuner is rotary-axial in operation and is said to provide closer linear calibration and tracking of the r-f and oscillator sections with respect to the rotary-axial motion applied to the component. The tuning device, which is only slightly larger than a flashlight battery, produces linear frequency tuning from 500 to 1600 kc–the complete range of the broadcast band. This range can be extended if desired.

RCA
New York, N.Y. . .

Radio Corporation of America (RCA) has instituted a new leasing plan which it believes to be suited to the individual requirements of users of RCA electronic data-processing equipment. The plan provides new economies in costs of operation for customers of RCA systems through four different rental agreements which are tailored for individual data processing needs. It will apply to the new RCA *301* and *601* systems going into use in 1961, as well as the RCA *501*, the first completely transistorized, medium-scale data-processing system. The new lease arrangements set basic monthly charges for different combinations of work requirements, resulting in a decrease in cost per unit as the work load increases. The four rental plans are designated as: unlimited availability, extended availability, random use, and single shift availability. Those customers who are currently operating on conventional agreements may remain on such agreements if they desire.



control center



switchboard

panelboard

enclosed circuit breaker

New and exclusive from Federal Pacific—Rotary Handle circuit breakers—the simplest, safest molded case breakers in the industry. Here is the one sure way to eliminate troublesome mechanical linkages . . . to forget all external mechanisms . . . to be absolutely certain of positive operation and true handle indication. Integral cylinder lock and locking ring for up to three padlocks are standard on all breakers. Federal Pacific breakers can be locked "on" or "off" independent of door position. Four frame sizes—15 to 800 amperes—meet all requirements for panelboards, switchboards, control centers and individually enclosed circuit breakers. Write for Bulletin 1425, Dept. FP-4, Federal Pacific Electric Company, Newark 1, New Jersey.

FEDERAL PACIFIC ELECTRIC COMPANY

FPE

growth through creative energy

Trade Literature . . .

"Micro Tips #29" . . .

This publication contains ideas submitted by plant engineers and electricians showing how they have used snap-action switches to increase production efficiency. Illustrated by drawings and photographs, this 29th issue contains five methods which can save man-hours, protect operators and machinery, and eliminate waste. The lead story tells how 34 precision-lighted pushbutton switches help fans keep pace with speedway racing action. *Micro-Switch, Div. of Minneapolis-Honeywell Regulator Co., Freeport, Ill.*

Textile Lighting . . .

The importance of improved lighting in textile mills is the subject of this 12-page, 2-color publication. Titled "Higher Profits Through Better Textile Lighting," the booklet establishes that better lighting means such benefits as increased production, reduced costs, fewer accidents, fewer rejects, improved employee morale, better plant housekeeping, and less maintenance. The economics of relighting is analyzed, and case histories describing the relighting experience of several companies are presented. *Inquiry Bureau (EH-60), General Electric Co., Nela Park, Cleveland 12, Ohio.*

Special Purpose Computers . . .

A new concept in the design and application of special computers brings modern computing and data-handling equipment within the range of small business firms. Advantages of special purpose computers in terms of low initial investment and minimum upkeep are described in a 4-page brochure offered by *Lockheed Electronics Co., U. S. Highway 1, Metuchen, N. J.*

High Performance Liquid Epoxy . . .

A new, 2-component, liquid epoxy insulating system for high performance electrical-electronic equipment has been specifically developed to meet the requirements of MIL-I-16923C, types *B, C,* and *D.* As such, it is outstanding in its balanced electrical, thermal, and physical properties. Write for Bulletin E-291, *Electrical Insulation Division, Hysol Corp., Olean, N. Y.*

"Water Bill U.S.A." . . .

The story of water and the huge money outlay necessary to pay our annual water bill each year is told in a new 16-page booklet entitled "Water Bill U.S.A." The booklet discusses the growing water problem, and tells of ways in which Americans are working to solve it with better farming practices and watershed control programs. Copies of Form DO41 may be obtained through Caterpillar dealers or from *the Advertising Division, Caterpillar Tractor Co., Peoria, Ill.*

Monthly Newsletter: "Radiation Review" . . .

A monthly newsletter, "Radiation Review" will be directed to users of high-voltage particle accelerators for research, and electron accelerators for industrial processing. The bulletin will publish newsworthy and informative feature material such as a series of suggested nuclear physics experiments using a high beam current accelerator. Planned features include tables and nomographs pertaining to radiation or ion beam technology, practical applications of the electron accelerator, and description of developments in areas of nuclear physics research with high-current accelerators. "Radiation Review" will be sent monthly without charge upon written request to: *Dept. RR-1, Radiation Dynamics, Inc., Westbury, L. I., N. Y.*

Safe Winter Driving . . .

Two new booklets help drivers of both trucks and passenger cars overcome the hazards of winter driving. "Keep Rolling with Safety in Winter Weather," aimed at the driver of trucks, buses, and commercial vehicles, outlines the six major hazards of winter driving, including increased braking distances and the effect of temperature on starting and stopping. For passenger car drivers, "Be a Winter Winner" relates the best methods of starting, stopping, and maintaining traction while traveling through snow and ice. Use of tire chains is emphasized in both booklets, and both include an 11-point checklist of essentials for preparing vehicles for the winter driving season. Single sample copies of both booklets may be obtained from the *National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.*

Electric Fintube Airduct Heaters . . .

Specification data, drawings, illustrations, and operating charts are provided in a 6-page booklet on Chromalox electric Fintube airduct heaters. Applications covered in the copy are: central heating, reheat after dehumidification, auxiliary heating, zone control, old and new duct systems, and others. Also given prominent treatment is a variety of Chromalox thermostats and contactors available for use with the scores of duct heater units. Request booklet F40100-1, from *Edwin L. Wiegand Co., 7500 Thomas Blvd., Pittsburgh 8, Pa.*

Electric Heat Booklet . . .

Just issued is a revised and enlarged edition of the booklet "How to Insulate Your Home for Electric Heating." Major changes include sections on the new "R" (installed resistance) method of specifying how much insulation is needed, the installation of insulation, proper ventilation, and various types of electric house heating equipment.

Single copies of the booklet are available free of charge from *National Mineral Wool Association, Rockefeller Center, 1270 Sixth Ave., New York 20, N. Y.*

Adhesives Selector Chart . . .

This Selector Chart shows the outstanding properties of key adhesives and hardeners, their tensile shear strengths at different temperatures and in several fuels. The operating temperature range, izod impact, coefficient of thermal expansion, and numerous other criteria are indicated. Bulletin A-100 fits into regular 3-ring binders or, when folded out, makes an easy reference wall chart. *Adhesives Dept., Hysol Corp., Olean, N. Y.*

Thermoelectricity Bibliography . . .

A complete bibliography on thermoelectricity includes a critical commentary on each of the listed articles, which, the publisher believes, may serve to indicate to an engineer those articles which would be of interest to him. *AMP Incorporated, Harrisburg, Pa.*

(Continued on page 47A)

Trade Literature

(Continued from page 44A)

Technical Bulletin . . .

Technical Memorandum No. 1, "Statistical Data Reduction and Control Systems," discusses methods for increasing efficiency of data reduction and automation systems for quality control, continuous processing, and large scale experimental work. Need for statistical reduction of data prior to readout is stressed. Dr. E. J. Schubert, Technical Director, is author of the 9-page bulletin. *Monitor Systems, Inc., Dept. 1, Fort Washington Industrial Park, Fort Washington, Pa.*

Engineering Design Manual . . .

A 76-page illustrated Engineering Design Manual (Bulletin 212 G) offers a compiled listing of materials and specifications, recommended application, and the latest technique for mounting tubing, wiring, and similar hardware. Also included is a description of the complete line of clamps, brackets, shims, and line supports for almost any application. *TA Mfg. Co., Engineering Dept., 4607 Alger St., Los Angeles 39, Calif.*

Thermocouple Selector Switches . . .

A 4-page catalog on several new designs in compact multipoint thermocouple selector switches describes how these switches may be used for temperature checking applications, such as when temperature being sensed by a number of thermocouples must be checked frequently or switched from one instrument to another, to average several temperature readings, or to switch a measuring instrument to different measuring points. Described in detail are the rotary switch with 6-, 12,- or 24-point capacity; key switches for up to 144 points, and push-button models for up to 72 point operation. Drawings and photographs illustrate the text. Information is given regarding minimum space requirements necessary for wall, bench, rack, or panel mounting, and data is provided on construction, termination arrangements, internal wiring specifications, and cabinet designs available for difficult installation situations. Switch components are described as to materials, mechanical operation, and servicing ease, to facilitate selecting a unit of exactly the right specifications for thermocouple or resistance thermometer applications. *Thermo Electric Co., Inc., Saddle Brook, N. J.*

Roll Grinding Wheels . . .

A 4-page brochure on roll grinding wheels describes the desired wheel characteristics required for all types of modern roll grinding, including good balance, fast cutting action and rapid stock removal. Photographs of various types of roll grinding wheels are included, as well as actual case histories for grinding such materials as hot mill work rolls, cold mill work rolls (tin mill, chilled iron and forged steel), and cast steel back up rolls. Complete roll grinding wheel recommendations and an illustration of a typical roll grinding department in a large rolling mill complete the literature. The brochure may be obtained from *The Macklin Co., Jackson, Mich.*

Arrow Electronics Price List . . .

A 1961, 8-page brochure lists more than 130 industrial electronic equipment lines. These lines are offered at manufacturer prices or better with off-the-shelf service. Designed to simplify the buyer's job, the guide is available free of charge from *Arrow Electronics, Inc., 525 Jericho Tpke., Mineola, L. I., N. Y.*

Potentiometer Catalog . . .

A 2-color 6-page brochure outlines precision wire-wound potentiometers and turns-counting dials. The catalog contains complete technical specifications and dimensioned mounting diagrams for all models of precision potentiometers and turns-counting dials stocked locally for immediate delivery at distributors throughout the United States and Canada. *Spectrol Electronics Corp., 1704 South Del Mar Ave., San Gabriel, Calif.*

Semiconductor Catalog . . .

A 24-page catalog covers over 800 semiconductor devices, including ratings, characteristics, and descriptive data on silicon glass diodes, silicon small-power, medium-power, and high-power rectifier cells, high-voltage cartridge rectifiers, zener diodes and reference elements, silicon controlled rectifiers, silicon and selenium rectifier stacks, silicon solar cells, and selenium contact protectors. Also included is a comprehensive listing of JEDEC rectifier types, with cross reference to device classification, rating, and page number. Use your letterhead to request "Short Form Catalog." *International Rectifier Corp., El Segundo, Calif.*

Squirrel Cage Induction Motors . . .

A 12-page bulletin on squirrel cage induction motors on basic drip-proof designs covers horsepower ranges from 1 to 150 hp. The pamphlet outlines squirrel cage motor applications, performance characteristics of squirrel cage motors, mechanical design variations, construction details, insulation details, ratings, and dimensions. *Century Electric Company, 18th & Pine Sts., St. Louis 3, Mo.*

Delay Lines Booklet . . .

A 12-page, fully illustrated facilities brochure, "Advancing The Art of Delay Lines," is available free to those requesting it on company letterheads. The book completely details the process which the manufacturer pursues in the designing and manufacturing of its delay line units. *ESC Electronics Corp., 534 Bergen Blvd., Palisades Park, N. J.*

Industrial Research Guidebook to N.Y.S. . .

The 1960 "Directory of Industrial Research Laboratories in New York State" lists more than 1,000 commercial and private research and testing laboratories, their special research fields, names of their executives, and the number of scientists and engineers they employ. The 280-page directory identifies research and development in New York as a billion-dollar industry. A 60-page subject index in the publication provides convenient reference to the various laboratories according to the scientific fields served. Research facilities are also listed alphabetically and by their location in the 10 major research complexes in the State. The State's 10 major research areas are described in detail in a geographic appendix which defines the special characteristics and advantages of each area. The 1960 edition of the Commerce Department publication, revising its 1954 directory, shows an increase of 450 laboratories in the State over the 6-year period. It is designed to supplement the promotional efforts of Governor Rockefeller's Advisory Council for the Advancement of Industrial Research and Development. Copies of the directory may be obtained from the Department's regional offices located throughout the State, or by writing *the New York State Department of Commerce, 112 State St., Albany 7, N. Y.*

(Continued on page 50A)

GENERAL FOREMAN, Maintenance Department, M.E. or E.E., with a minimum of five years' experience in the foundry industry. Job involves supervisory responsibility for all maintenance department personnel and several shift foremen in steel foundry. Location, Pennsylvania. W9783.

FIELD SERVICE REPRESENTATIVE, with some formal electronic training either as a technician or engineer and be familiar with magnetic amplifiers. To work on installation and trouble-shooting on instruments and control equipment for Naval nuclear reactor plants. Must be willing to travel. Salary open. Location, Connecticut. W9782.

ENGINEERS. (a) Senior Engineer, Electronic, M.S.E.E., with eight to ten years' experience in RF design, equipment design. Experience should be in production rather than research. (b) Senior Engineer, with six to eight years' experience. Education and experience same as above. (c) Chief Product Engineer, preferably M.E. and E.E., with strong background in electronic orientation, with ten to 15 years' applicable experience mostly in electronic packaging and in production engineering. Salaries: (a) $14,000-$16,000 a year; (b) $12,000-$15,000 a year; (c) $12,000-$15,000 a year. Location, Maryland. W9781.

ELECTRIC POWER SYSTEMS ENGINEER, graduate E.E., two to five years' experience in any of the following: (1) Systems planning, (2) protective relaying, auto controls on transmission, distribution, (3) design and construction of electric side of power plant substations. Salary, $6500-$9600 a year. Location, New York. W9780(a).

QUALITY CONTROL SUPERVISOR for electronic instrument production, with three to five years' experience and have a good knowledge of electronic theory and transistors. Salary open. Location, Upstate New York. W9775.

SENIOR PRODUCTION ENGINEER, M.E. or E.E., with seven to ten years' in company manufacturing small electro-mechanical devices. Salary, $9000-$10,000 a year. Location, New Jersey. W9772.

DIRECTOR OF ENGINEERING, E.E. graduate, with at least ten years' administrative design and development experience in electronic fields including hi-fi and radio kits. Salary, $15,000 a year minimum. Location, Midwest. W9767.

SALES ENGINEER, graduate, E.E., experience in the sale of distribution equipment to utilities supply houses, etc. Position will lead to Product Manager of Sales for Electric Conduit Division of company. Salary, $10,000-$12,000 a year. Location, New York City. W9766.

CHIEF TRANSISTOR DESIGNER, graduate E.E., to head up a section of five to six other engineers with ten years' experience, several years' of which should be in the application of transistors, magnetic cores in the telecommunications field. Salary, $18,000 a year plus profit sharing. Location, Connecticut. W9765.

MILL ENGINEER, B.S.M.E., B.S.E.E., with ten years' overall experience, three to five years' in the paper industry. To participate in selection of equipment, order major items and necessary auxiliaries; organize preventive maintenance procedures in the paper mill, etc. Salary, $9000-$10,000 a year. Location, New Jersey. W9765.

RESEARCH AND DEVELOPMENT ENGINEER, E.E., graduate with at least five years' experience on digital control systems. Knowledge of transistors required. Salary, $9000-$11,000 a year. Location, Connecticut. W9758.

TECHNICAL WRITERS, B.S. degree or equivalent, minimum of five years' of specific experience and an excellent electronic background. To supervise technical writers in the preparation of instruction manuals, be familiar with all related government specifications. Salary, $8500-$10,000 a year. Location, New Jersey. W9754.

ASSISTANT OR ASSOCIATE PROFESSOR in electrical engineering, to teach electronic and power subjects. Salaries and rank depending on education and experience. Location, eastern Pennsylvania. W9750(a).

MICROWAVE TUBE ENGINEERS OR KLYSTRON ENGINEERS, B.S., M.S. and Ph.D. in electrical engineering or physics, with one or more years' of microwave experience, for R & D, design or production engineering in a microwave tube lab. Company will pay placement fee. Location, Upstate New York. W9746.

JUNIOR ELECTRICAL ENGINEER, graduate with equipment experience for testing permanent magnets. Salary, $6000-$8000 a year. Location, New Jersey. W9731.

DESIGNER, electric motors, graduate electrical, senior or junior; must have several years' experience on actual design of small electric AC-DC motors and generators. Will be responsible for complete design from conception to production. Salary, to $12,000 a year depending upon experience. Location, San Francisco Peninsula. W9717.

ENGINEERS. (a) Production Manager, electrical graduate, with knowledge of digital techniques helpful. Heavy experience in supervising production engineers, foremen and assistant assembly foremen, short order production and production control. Experience in the field of electronic communications. Salary, to $18,000 a year. (b) Section Head, advanced degree in electrical engineering, and a minimum of three to five years' experience in supervising engineers and technicians. Heavy digital circuitry with computer application and magnetic core experience. Salary, to $18,000 year. Location, Connecticut. W9716.

SALES ENGINEERS. (a) Industrial Sales Engineer, graduate mechanical, electrical, industrial or chemical, with four years' related experience, to be responsible for the promotion and sale of regulators, recorders, transmitters, valves and controllers of pressure, temperature and humidity to OEM accounts, processing industries, wholesalers and consulting engineers on a non-installed basis. Salary, $7200-$9600 a year, plus company maintained fringe benefits and profit-sharing program. Location, northern New Jersey. (c) Contract Sales Engineer, Trainee, graduate mechanical, electrical or industrial, with some training in refrigeration, heating and air conditioning. Will be given a planned program of training in sales office. This includes related job experience utilizing technical training. Salary, $6300-$7200 a year, plus company maintained fringe benefits including profit-sharing program. Company will pay placement fee. Location, upstate N.Y. W9712.

ENGINEERS. (a) Development Engineer, Microwave Tubes, graduate in physics or electrical engineering, with three to five years' experience in design and development of microwave tubes, preferably with millimeter klystrons or millimeter tubes. Salary, $8000-$10,000 a year. (b) Industrial Engineer, Electronics, I.E. degree, with a minimum of three years' experience to guide efficient setup of new manufacturing processes in conjunction with plant engineering, production and product engineers, study existing manufacturing procedures for improvements, propose and effectuate improvements, setup standard costs, provide cost estimates for quotation purposes. Should be able to design such jigs, fixtures, etc. Salary, $8000-$10,000 a year. Location, New York City. W9705.

SALES MANAGER, Electronics, Metallurgical or Chemical engineering graduate, experience in application of molybdenum and tungsten to electronics, welding and metal spraying industries, to control national marketing and sales functions. Salary, to $15,000 a year. Location, Maine. W9704.

JUNIOR ELECTRONIC ENGINEER OR PHYSICIST, graduate, interested in ceramics and capacitor materials. Salary, $6000-$6500 a year. Location, Middlesex County, New Jersey. W9690.

SENIOR ENGINEER, Acoustical, graduate electrical, with five years' practical and theoretical acoustical experience in the field of loud speaker application and design. Salary, $9400-$11,000 a year. Location, New Jersey Metropolitan area. W9688.

ELECTRICAL ENGINEER, with a minimum of five years' experience, for industrial plant electrical design; inspection surveys; major trouble shooting. Salary, $7800-$8400 a year. Location, Delaware. W9680.

SALES ENGINEER, preferably electrical graduate, to sell electrical timing devices, panels and systems, fire alarms, etc. to institutions, industry, etc. Must be capable of designing switching circuits. Salary plus commission and bonus; potential $8000-$10,000 a year; company furnishes car. Long Island territory; prefer Long Island resident. W9679.

ASSOCIATE EDITORS, electrical graduate, with experience in editorial work and five to eight years' experience in process industry, automated equipment installation and maintenance, for a trade publication. Salary, $7500-$9000 a year. Location, Midwest. W9667(a).

ENGINEERS. (a) Manufacturing Engineers, graduate electrical or mechanical, for manufacturing department, operations division, with five years' experience in analyzing producibility and solving fabrication and assembly problems of military electronic and electro-mechanical equipment; familiarity with prototype and production manufacture techniques. Heavy estimating on bid proposals, i.e., machine, sheet-metal, mechanical and electrical assembly. Salary, $8000-$10,000 a year. (b) Project Managers, electrical graduates, for product engineering department, military products division. Will be responsible for military communications product design and development. At least eight years' experience required in two or more of the following communication areas: RF transmission and receiving systems (UHF—Microwave), RF repeater systems (UHF—Microwave), Base Band systems, spectrum conservation techniques. Salary, $12,000-$16,000 a year. Company pays placement fees. Location, New York suburban area. W9657.

Chicago Office

DESIGN AND DEVELOPMENT ENGINEER, B.S. or M.S.E.E., with three or more years' in radio interference field. Design and development radio noise filters for aircraft missile equipment. Familiar with space technology; lab specs. and military specs. and use of magnetic materials as applied to filter design. Must be U.S. citizen for manufacturer. Employer will pay placement fee. Salary, $9600-$12,000 a year. Location, Seattle, Washington. C8345.

ELECTRICAL ENGINEER, B.S., or equivalent by experience. Duties will involve responsible charge for electrical engineering work in field of electric utilities, industrial and commercial building design and considerable related administrative duties. Position open in Colorado, Arizona and will likely have such positions open in several foreign localities within the next several months. For a consulting engineer. Salary, to $10,000 a year. C8344.

ELECTRICAL SYSTEMS ENGINEER, B.S. or M.S. in electrical engineering, with four to eight years' experience in two or more of the following areas: (a) Transistor and controlled rectifier circuit design and development; (b) magnetic amplifier development; (c) control systems design and development for motors and/or generators; (d) servo-system design and development. Duties: Applied research and development in the advanced development group on static inverters and converters and systems ranging from 1-1000 KVA. Particular emphasis is applied to various advanced types of power supplies and rive systems. Salary, $9000-$12,000 a year. Location, southern Wisconsin. C8342.

Shown here is a section of final testing area. Voltage tests are being applied to *full reel lengths* of cable before shipment.

ANOTHER BIG REASON WHY YOU SHOULD CONSIDER ANACONDA BUTYL (AB) CABLE—

SPECIALIZED QUALITY CONTROL AND INSPECTION

From the start: Raw-material suppliers are required to submit certified test reports. Then, tests and sampling at our plant offer extra protection even before production begins. **To finish:** Here's the final inspection line where the finishing touches are applied and where every inch of cable is carefully inspected. Perhaps you already know that Anaconda test procedures are much above industry standards. But do you know that test voltages on Anaconda Butyl (AB) Cable are 125% of industry standards—that minimum corona level is 150% of rated voltage to ground?

Quality control at Anaconda is *more* than mere testing and inspection. It is built into every manufacturing step. That's why you can be sure your Anaconda cable will be of high quality—why you can be sure Anaconda Butyl (AB) Cable is the finest rubber-insulated cable you can buy.

Everything you need to know about Anaconda Butyl (AB) high-voltage cable is neatly summed up in a new booklet, DM-5903, "Anaconda High-Voltage Durasheath* Cable." For your copy, write to: Anaconda Wire & Cable Co., 25 Broadway, New York 4, N. Y. *Reg. U.S. Pat. Off. 60230

ASK THE MAN FROM

ANACONDA®

ABOUT BUTYL (AB) HIGH-VOLTAGE CABLE

ELECTRICAL ENGINEER, graduate E.E., major in math, with two or more years' experience. Work will entail projections of the electrical industry statistical work writing reports and contacting client companies. Travel about 25% of time to clients companies, must be an American citizen, preferably married, for a utility business. Employer will negotiate placement fee. Salary, to $9000 depending on experience. E8334.

UTILITY ENGINEER, B.S.E.E., planning design layout, electric power generation and distribution. Distribute records, transformer records, etc. Also similar work in water and sewer utility. Some operation in coordinating line and service crews, for public utility. Employer will pay placement fee. Salary, $7500 a year. Location, Arkansas. C8330.

SUPERVISOR OF ELECTRICAL CONTROLS ENGINEERING, graduate electrical; ten or more years' experience in design and development of electrical controls. Must have creative mind and managerial ability. Must be U.S. citizen for a manufacturer of heavy industrial equipment. Salary, $12,000 a year. Employer will pay placement fee. Location, southern Wisconsin. C8237.

San Francisco Office

INSTRUMENTATION DESIGNER, EE, ME or equivalent. At least five years' experience application and systems design of instrumentation for chemical, petrochemical or petroleum plants. Should be able to provide complete design function with minimum of supervision. Salary commensurate. Relocation allowance and employer will pay placement fee. For engineering builder. San Francisco Sj-5655-R.

SYSTEM RESOURCES AND POWER CONTRACTS ENGINEER, EE and experience in similar work or in distribution and transmission problems. Make special studies regarding negotiating power purchases, sale agreements and wheeling charges with other companies and federal agencies, including investigation of all suitable alternative to transmission proposal and making estimates on feasibility, may involve dealing with power suppliers and other distributors and federal agencies. Salary open. Pacific Northwest. For utility. Sj-5650-R.

DESIGNER, EE, minimum three years solid state or mechanical switching pulsive and random noise filtering and understanding of STL 2617-A, associated military specifications; versed in usage, theory, etc., of magnetic materials as used in filter devices. To do original design of filters for radio noise in type of equipment used for aircraft and missiles, electronics and electromechanical equipment. $9000-12,000. Employer will reimburse placement fee after thirty days. Interview and moving expenses paid by employer. Pacific Northwest. Sj-5648.

(a) PRELIMINARY MISSILE DESIGN, analysis of both ballistic missiles and advanced space vehicles from control guidance and performance viewpoint, stressing propulsion system application. Two to eigth years related experience. (b) PROPULSION ENGINEERS, analysis and preliminary design of new types of propulsion system. About ten years related work experience required. (c) PROJECT AND DEVELOPMENT ENGINEERS, plans and schedules solid rocket project work. Develop solid rocket hardware or components. Three to five years experience required. For research and development in fields of solid and liquid propellants, rockets and advanced propulsion systems. Salaries open. San Francisco Bay Area. Sj-5643-R.

ELECTRIC TEST ENGINEER, EE or equivalent experience, 25-40. To head up test responsibilities including supervision of other departments. To design and test special transformers. Opportunity for advancement; for manufacturer of transformers for aircraft, missiles, radar and radio transmitters. $7200-9000. San Francisco East Bay. Sj-5640.

SUPERVISOR OF COMPUTOR ENGINEERING APPLICATION: EE, to continue development of engineering application of digital computor to problems of electric utility. Emphasis on distribution and transmission problems, net work studies, short circuit studies and water storage data for integrated hydro operation. Salary open, depending on experience. Pacific Northwest Sj-5625-R.

ENGINEERING MANAGER, EE, with at least six years electric utility experience, to manage engineering department of small, rapidly growing utility. $15,000-15,000. Alaska. Sj-5619-R.

DESIGNER, EE or ME, 30-45. Experienced design and development of packaging machinery, machine tools, materials handling (not bulk conveyors), textile machinery; knowledge of design and development of complex machinery and electromechanical devices. To do work from concept, design, through prototype fabrication and testing. For machinery manufacturer. $8400 up, San Francisco Peninsula. Sj-5606-R.

ELECTRONIC DESIGNER, Four-five years experience working with inertial guidance systems and supervision of technical personnel. Thoroughly trained and experienced in systems design of inertial equipment. Familiar with system design parameters, servo-systems and feedback analysis. To design electronic systems for inertial guidance equipment, involving circuit design employing semiconductor components in high quality amplifiers (AC and DC). Salary open. San Francisco East Bay. Sj-5604-R.

ELECTRONIC DESIGNER, EE or Electronic E. Solid technical background in designing electronic circuits. Familiar with computer terminology would be helpful. Experience required, one to three years circuit design. Citizenship not essential. To design electronic circuits for computer equipment, such as servo resolvers, amplifiers, pre-amplifiers, function generators, multipliers and other components. $6000-8400 plus profit sharing bonuses. San Francisco East Bay. Sj-5603-R.

JR ELECTRONIC ENGINEER, EE, or Electronic E, good school marks. Should have had training in electronic design in semi-conductor field. One year of experience in circuit design desirable. Previous summer employment in electronics helpful. Assist in design and development of electronic devices used in missile equipment and space vehicles under direction of project engineer. $6000-7200, plus profit sharing bonuses. San Francisco East Bay. Sj-5602-R.

DIGITAL COMPUTER DESIGN, at least two years' experience in design of digital data systems, EE, no age limit. To design digital computor systems. $7200-8400, depending on experience, plus profit sharing bonuses. San Francisco East Bay. Sj-5600-R.

TEST ENGINEER, EE, young. Qualified to establish and administer test procedures and data for application, specifications and safety of electric circuit breaker equip; such tests as high voltage, heavy current, 60-cycle impulse, temperature, life, mechanical. Able to report and evaluate result of such tests. For a manufacturer. $7000-9000. Los Angeles. Sj-5594.

SALES ASSISTANT, EE or equivalent, under 30. Some experience in application usage or sales of switchgear type equipment. Will assist sales engineer in application engineering bidding, bills of material, etc., train for sales job. For manufacturer's agent. About $8100. San Francisco. Sj-5589.

DEVELOPMENT, DESIGN, BS or MS, age open. Well qualified by experience to deal with engineering, specifications, checking and board work on missiles including missiles, launch standards, transport fuels and storage equipment; also including mechanical engineering for transport and shipping equipment for missile fuel. Some clearance required. For consultant. $5.00-$7.00 per hour. San Francisco Peninsula. Sj-5586.

ENGINEERING TEACHERS: (a) EE, MS and U. S. Citizen. Should have specialized in electromechanical energy conversion of analog and/or digital computor theory. Will be expected to handle general underground material in Electrical Engineering. (b) CE, MS and some teaching experience, U.S. citizen. To teach mechanics of materials, materials lab, structures and soil mechanics. $3,000 for one-half year; $6,000 for nine months. Central California. Sj-5577.

DISTRIBUTION ENGINEER: 28-35. Experience in actual construction and maintenance work on substation, underground, overhead and shop; able to handle construction crews through foreman. Will search for improved methods working from basic engineering designs and able to work with power plant and transmission divisions of an electric utility. Good promotional opportunity. For man well based technically and with good practical outlook. To $8400. Pacific Islands. Sj-5548.

Trade Literature

(Continued from page 47A)

Insulating Materials Properties Chart . . .

A quick informational reference for engineers in search of high-temperature insulation materials for electrical, electronic, avionic and nuclear applications is this completely revised, up-to-date engineering "Compara Chart" which details the commonly-used plastic and ceramic insulating materials, including the various formulations of Supramica ceramoplastics and Mycalex glass-bonded mica. The 4-page leaflet also includes a listing of the Fahrenheit temperature limits for 88 materials, and a table of thermal expansion coefficients of 57 widely used insert metals and insulating materials. *Mycalex Corp. of America, 125 Clifton Blvd., Clifton, N. J.*

Industrial Plastics Catalog . . .

A 216-page plastics catalog gives technical information for machining, and forming and processing plastics such as Teflon, Kel-F, Nylon, Styrene, epoxies and Permali laminates. Specific information on dielectric insulation, tensile strengths, hardness, deformation, moisture and water resistance, linear expansion and contraction characteristics is included. Molding methods for Fiberglas filled molding powders and epoxy fluidizer coatings are given in the booklet as are pressure-temperature selection charts, engineering facts, and machining and forming instructions for rods, tubes, sheets, film, shapes, gaskets, bellows, and laminated plastics. The catalog also carries information on antifriction coatings, insulated wire and cable, industrial electrical tapes, and aerosol sprays. *R. S. Hughes Co., Inc., 4515 Alger St., Los Angeles 39, Calif.*

(Continued on page 53A)

Trade Literature

(Continued from page 50A)

Thorium Reactor Project . . .

The 1960 Research and Development Report on the Advanced Epithermal Thorium Reactor project reflects completion of the first year of research and development under Phase II of a program being conducted for Southwest Atomic Energy Associates by Atomics International to help produce economic electric power from atomic energy. Included is a report on the design and construction of the Epithermal Critical Experiment Laboratory. A critical experiment machine is being installed and will be in operation shortly. *Public Relations Dept., Atomics International, P.O. Box 309, Canoga Park, Calif.*

"Screw Descriptor" . . .

A new device to supply correct nomenclature when purchasing screw products is said to solve basic problems in properly identifying heads, washers, and threads when ordering screws. The "Screw Descriptor" accomplishes this by means of two revolving dials, and by showing pictures and giving correct nomenclature for numerous heads, threads, and washers. The "Screw Descriptor" is a handy 9½ by 9½ inches, and has a decimal equivalent chart printed on the reverse side. The "Descriptor" will be sent free of charge to anyone making the request on a company letterhead. *Dept. 195, Active Screw & Mfg. Company, 4250 N. Pulaski Rd., Chicago 41, Ill.*

Algebraic Compiler . . .

A self-teaching manual which makes it possible for engineers and scientists to master their compiler has been made available by this computer division. Based on ALGOL, the international algebraic language, the new compiler permits engineers, mathematicians, and scientists to program the general-purpose compiler in universal mathematical language. The 32-page manual describes the language, and sets forth the procedures for the representation of numerical data and control statements. Step-by-step examples illustrate the principles and operational characteristics of the compiler. Also included is a complete typical program. Request the G-15 Algo manual from *Bendix Corp., Computer Div., Los Angeles 45, Calif.*

SCAM®

DE-LINE

THE ENGINEER'S

ANNUNCIATOR

GREATEST FLEXIBILITY IN THE FIELD

Available In Many Sequences

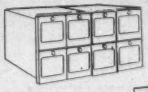
BACK-LIGHTED NAME PLATE — OR — BULL'S-EYE

AND

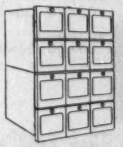
Twin-point can replace single point in field with no change in cabinet wiring.

Side By Side Or Stacked

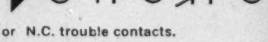
DE-LINE modular design retains original custom cabinet appearance as system grows.



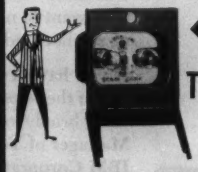
You save up to 50% panel area and still have full size legend plates. DE-LINE plug-ins are self-policing.



AUXILIARY CONTACTS N.O.—N.C. standard with most plug-ins.



SAME PLUG-IN operates from N.O. or N.C. trouble contacts.

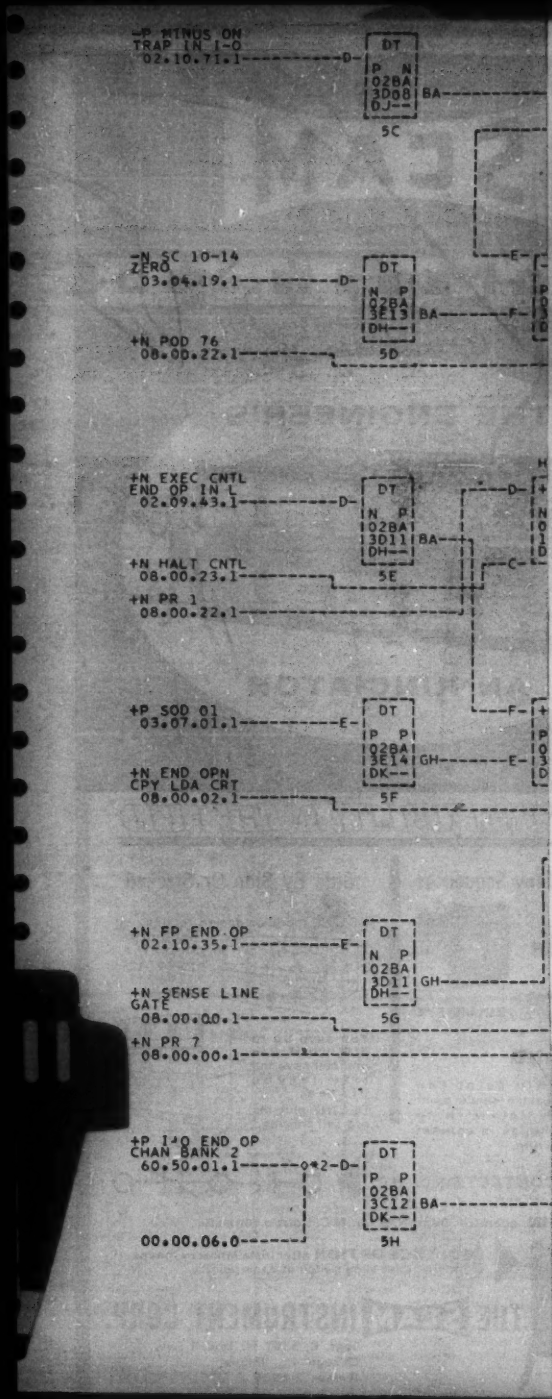


SEQUENCE OPTION after installation by means of independent slide switch at each point.

THE SCAM INSTRUMENT CORP.

Dept. C, 3101 N. Lowell Ave.
Chicago 41, Illinois
Avenue 2-6930

REPRESENTATIVES IN ALL PRINCIPAL CITIES • COMPLETE MONITORING SYSTEMS FOR INDUSTRY



Opportunities in Systems Development

Automating design to take out the drudgery

This circuit design was printed by a computer.

IBM engineers did the creative work, specifying the logic functions desired and the circuits that would do the job most efficiently. The machine then checked this design. After the errors had been corrected, the computer determined the proper panel wiring, weighing such parameters as inductive noise, lengths of wires in alternative routes, and types of wires.

Freeing engineers for engineering

In addition to printing out the circuit, in the form shown at left, the computer automatically produced 20 other documents. These included panel wiring data, wiring bills of material, systems pages, summary lists, and card location charts. Engineers are spared the drudgery of this tedious work; and documents are complete and error-free.

Developing this system took the skills and imagination of a team of mathematicians and engineers in research, development and manufacturing. It also required the progressive spirit of a company eager to maintain its leadership in systems design and development.

Careers in many areas

You may be interested in areas other than computer circuitry, such as the pioneering work IBM is doing in optics, or cryogenics, or microwaves, or human factors engineering. At IBM there are a number of openings that offer worlds of opportunity to those individuals who want to make important progress on the frontiers of science and technology.

If you have a degree in engineering, mathematics, or one of the sciences, plus experience in your field, please write briefly, outlining your qualifications, to:

Manager of Technical Employment
IBM Corporation, Dept. 550Z
590 Madison Avenue
New York 22, N. Y.

IBM®

INTERNATIONAL BUSINESS MACHINES CORPORATION